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Research article

Reduction of carbon emissions under sustainable supply chain management with uncertain human learning

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Appendix 1

Inventory holding cost for the manufacturer in each production cycle will be

$H_M \int_{t_o}^{T} I_M(t)dt = \frac{H_M P(T-t_o)^2}{2}$

Manufacturing cost $= C_M P(T - t_o)$
Setup cost of manufacturer $= C_{OM}$
Screening cost $= C_{SM} P(T - t_o)$
Waste disposal cost $= C_W P_3 P(T - t_o)$

Total cost of transportation $= \sum_{i=1}^{n} C_{TM_i} P_1 P(T - t_o) + C_{TA} P_2 P(T - t_o)$

Appendix 2

Shortage cost of the i^{th} retailer

$$= C_{B_i} \int_{T_2}^{2T} (-I_{R_{i3}}(t))dt = \frac{C_{B_i}}{2}\left(\frac{{S_i}^2}{B_i D_i}\right)$$

Lost sale cost of the i^{th} retailer

$$= C_{L_i}\int_{T_2}^{2T}(1-B_i)D_i dt = C_{L_i}(1-B_i)(\frac{S_i}{B_i})$$

Holding cost of the i^{th} retailer

$$= H_{R_i}\left(\int_{T}^{T_1} I_{R_{i1}}(t)dt + \int_{T_1}^{T_2} I_{R_{i2}}(t)dt\right) + H_{WR_i}(\frac{(Q_i)^2 p_i(m)}{x_i})$$

$$= H_{R_i}[\frac{(Q_i)^2(1-p_i(m))^2}{2D_i\log\left(\frac{1+l_i+k_i(\epsilon)-T}{1+l_i+k_i(\epsilon)-2T+\frac{S_i}{B_iD_i}}\right)} + \frac{D_i}{4}((1+l_i+k_i(\epsilon)-2T+\frac{S_i}{B_iD_i})^2-(1+l_i+k_i(\epsilon)-T)^2) +$$

$$\frac{Q_i}{2(1+l_i+k_i(\epsilon)-T)}(\frac{(Q_i)^2(1-p_i(m))^2}{D_i\log\left(\frac{1+l_i+k_i(\epsilon)-T}{1+l_i+k_i(\epsilon)-2T+\frac{S_i}{B_iD_i}}\right)^2} - (1+l_i+k_i(\epsilon)-T)^2)] + H_{WR_i}(\frac{(Q_i)^2 p_i(m)}{x_i})$$

Cost of screening of product for the i^{th} retailer $= C_{SR_i}Q_i$

Cost of placing an order for the i^{th} retailer $= C_{OR_i}$

Wholesale purchasing price of the i^{th} retailer $= w_iQ_i$

Advertisement cost for the i^{th} retailer $= NC_{A_i}$

Preservation technology cost $= \epsilon\ T$

Deterioration cost of the i^{th} retailer

$$= H_{DR_i}[\int_{T}^{T_1}\left(\frac{1}{1+l_i+k_i(\epsilon)-t}\right)(D_i(1+l_i+k_i(\epsilon)-t)\log\left(\frac{1+l_i+k_i(\epsilon)-t}{1+l_i+k_i(\epsilon)-T}\right) + \left(\frac{1+l_i+k_i(\epsilon)-t}{1+l_i+k_i(\epsilon)-T}\right)Q_i)dt$$

$$+\int_{T_1}^{T_2}\left(\frac{1}{1+l_i+k_i(\epsilon)-t}\right)(D_i(1+l_i+k_i(\epsilon)-t)\log\left(\frac{1+l_i+k_i(\epsilon)-t}{1+l_i+k_i(\epsilon)-2T+\frac{S_i}{B_iD_i}}\right))dt]$$

$$= H_{DR_i}[Q_i - \frac{(Q_i)^2(1-p_i(m))}{D_i(1+l_i+k_i(\epsilon)-T)\log\left(\frac{1+l_i+k_i(\epsilon)-T}{1+l_i+k_i(\epsilon)-2T+\frac{S_i}{B_iD_i}}\right)} - D_i(T-\frac{S_i}{B_iD_i}) + Q_i(1 - p_i(m))]$$

Appendix 3

$$\widetilde{C_M} = \left(C_M - \Delta_{C_M}^l, C_M, C_M - \Delta_{C_M}^u\right), 0 < \Delta_{C_M}^l < C_M \ and\ 0 < \Delta_{C_M}^u$$

$$\widetilde{C_W} = \left(C_W - \Delta^l_{C_W}, C_W, C_W - \Delta^u_{C_W}\right), 0 < \Delta^l_{C_W} < C_W \; and \; 0 < \Delta^u_{C_W}$$

$$\widetilde{C_{OM}} = \left(C_{OM} - \Delta^l_{C_{OM}}, C_{OM}, C_{OM} - \Delta^u_{C_{OM}}\right), 0 < \Delta^l_{C_{OM}} < C_{OM} \; and \; 0 < \Delta^u_{C_{OM}}$$

$$\widetilde{C_{SM}} = \left(C_{SM} - \Delta^l_{C_{SM}}, C_{SM}, C_{SM} - \Delta^u_{C_{SM}}\right), 0 < \Delta^l_{C_{SM}} < C_{SM} \; and \; 0 < \Delta^u_{C_{SM}}$$

$$\widetilde{C_{TA}} = \left(C_{TA} - \Delta^l_{C_{TA}}, C_{TA}, C_{TA} - \Delta^u_{C_{TA}}\right), 0 < \Delta^l_{C_{TA}} < C_{TA} \; and \; 0 < \Delta^u_{C_{TA}}$$

$$\widetilde{C_{PA}} = \left(C_{PA} - \Delta^l_{C_{PA}}, C_{PA}, C_{PA} - \Delta^u_{C_{PA}}\right), 0 < \Delta^l_{C_{PA}} < C_{PA} \; and \; 0 < \Delta^u_{C_{PA}}$$

$$\widetilde{C_{TM_\iota}} = \left(C_{TM_i} - \Delta^l_{C_{TM_i}}, C_{TM_i}, C_{TM_i} - \Delta^u_{C_{TM_i}}\right), 0 < \Delta^l_{C_{TM_i}} < C_{TM_i} \; and \; 0 < \Delta^u_{C_{TM_i}}$$

$$\widetilde{C_{OR_\iota}} = \left(C_{OR_i} - \Delta^l_{C_{OR_i}}, C_{OR_i}, C_{OR_i} - \Delta^u_{C_{OR_i}}\right), 0 < \Delta^l_{C_{OR_i}} < C_{OR_i} \; and \; 0 < \Delta^u_{C_{OR_i}}$$

$$\widetilde{C_{SR_\iota}} = \left(C_{SR_i} - \Delta^l_{C_{SR_i}}, C_{SR_i}, C_{SR_i} - \Delta^u_{C_{SR_i}}\right), 0 < \Delta^l_{C_{SR_i}} < C_{SR_i} \; and \; 0 < \Delta^u_{C_{SR_i}}$$

$$\widetilde{C_{B_\iota}} = \left(C_{B_i} - \Delta^l_{C_{B_i}}, C_{B_i}, C_{B_i} - \Delta^u_{C_{B_i}}\right), 0 < \Delta^l_{C_{B_i}} < C_{B_i} \; and \; 0 < \Delta^u_{C_{B_i}}$$

$$\widetilde{C_{L_\iota}} = \left(C_{L_i} - \Delta^l_{C_{L_i}}, C_{L_i}, C_{L_i} - \Delta^u_{C_{L_i}}\right), 0 < \Delta^l_{C_{L_i}} < C_{L_i} \; and \; 0 < \Delta^u_{C_{L_i}}$$

$$\widetilde{H_M} = \left(H_M - \Delta^l_{H_M}, H_M, H_M - \Delta^u_{H_M}\right), 0 < \Delta^l_{H_M} < H_M \; and \; 0 < \Delta^u_{H_M}$$

$$\widetilde{H_{R_\iota}} = \left(H_{R_i} - \Delta^l_{H_{R_i}}, H_{R_i}, H_{R_i} - \Delta^u_{H_{R_i}}\right), 0 < \Delta^l_{H_{R_i}} < H_{R_i} \; and \; 0 < \Delta^u_{H_{R_i}}$$

$$\widetilde{H_{WR_\iota}} = \left(H_{WR_i} - \Delta^l_{H_{WR_i}}, H_{WR_i}, H_{WR_i} - \Delta^u_{H_{WR_i}}\right), 0 < \Delta^l_{H_{WR_i}} < H_{WR_i} \; and \; 0 < \Delta^u_{H_{WR_i}}$$

$$\widetilde{H_{DR_\iota}} = \left(H_{DR_i} - \Delta^l_{H_{DR_i}}, H_{DR_i}, H_{DR_i} - \Delta^u_{H_{DR_i}}\right), 0 < \Delta^l_{H_{DR_i}} < H_{DR_i} \; and \; 0 < \Delta^u_{H_{DR_i}}$$

$$\tilde{\epsilon} = (\epsilon - \Delta^l_\epsilon, \epsilon, \epsilon - \Delta^u_\epsilon), 0 < \Delta^l_\epsilon < \epsilon \; and \; 0 < \Delta^u_\epsilon$$

Appendix 4

$$d(\widetilde{C_M}, \tilde{0}) = \frac{(C_M - \Delta^l_{C_M}) + 2C_M + (C_M + \Delta^u_{C_M})}{4} = C_M + \frac{(\Delta^u_{C_M} - \Delta^l_{C_M})}{4},$$

$$\Delta^l_{C_M} > 0 \; and \; \Delta^l_{C_M} > 0$$

Similarly,

$$d\left(\widetilde{C_W}, \tilde{0}\right) = C_W + \frac{\left(\Delta^u_{C_W} - \Delta^l_{C_W}\right)}{4}, \Delta^l_{C_W} > 0 \; and \; \Delta^l_{C_W} > 0$$

$$d\left(\widetilde{C_{OM}}, \tilde{0}\right) = C_{OM} + \frac{\left(\Delta^u_{C_{OM}} - \Delta^l_{C_{OM}}\right)}{4}, \Delta^l_{C_{OM}} > 0 \; and \; \Delta^l_{C_{OM}} > 0$$

$$d\left(\widetilde{C_{SM}}, \tilde{0}\right) = C_{SM} + \frac{\left(\Delta^u_{C_{SM}} - \Delta^l_{C_{SM}}\right)}{4}, \Delta^l_{C_{SM}} > 0 \; and \; \Delta^l_{C_{SM}} > 0$$

$$d\left(\widetilde{C_{TA}},\tilde{0}\right) = C_{TA} + \frac{\left(\Delta^u_{C_{TA}} - \Delta^l_{C_{TA}}\right)}{4}, \Delta^l_{C_{TA}} > 0 \; and \; \Delta^l_{C_{TA}} > 0$$

$$d\left(\widetilde{C_{PA}},\tilde{0}\right) = C_{PA} + \frac{\left(\Delta^u_{C_{PA}} - \Delta^l_{C_{PA}}\right)}{4}, \Delta^l_{C_{PA}} > 0 \; and \; \Delta^l_{C_{PA}} > 0$$

$$d\left(\widetilde{C_{TM_\iota}},\tilde{0}\right) = C_{TM_i} + \frac{\left(\Delta^u_{C_{TM_i}} - \Delta^l_{C_{TM_i}}\right)}{4}, \Delta^l_{C_{TM_i}} > 0 \; and \; a^l_{C_{TM_i}} > 0$$

$$d\left(\widetilde{C_{OR_\iota}},\tilde{0}\right) = C_{OR_i} + \frac{\left(\Delta^u_{C_{OR_i}} - \Delta^l_{C_{OR_i}}\right)}{4}, \Delta^l_{C_{OR_i}} > 0 \; and \; \Delta^l_{C_{OR_i}} > 0$$

$$d\left(\widetilde{C_{SR_\iota}},\tilde{0}\right) = C_{SR_i} + \frac{\left(\Delta^u_{C_{SR_i}} - \Delta^l_{C_{SR_i}}\right)}{4}, \Delta^l_{C_{SR_i}} > 0 \; and \; \Delta^l_{C_{SR_i}} > 0$$

$$d\left(\widetilde{C_{B_\iota}},\tilde{0}\right) = C_{B_i} + \frac{\left(\Delta^u_{C_{B_i}} - \Delta^l_{C_{B_i}}\right)}{4}, \Delta^l_{C_{B_i}} > 0 \; and \; \Delta^l_{C_{B_i}} > 0$$

$$d\left(\widetilde{C_{L_\iota}},\tilde{0}\right) = C_{L_i} + \frac{\left(\Delta^u_{C_{L_i}} - \Delta^l_{C_{L_i}}\right)}{4}, \Delta^l_{C_{L_i}} > 0 \; and \; \Delta^l_{C_{L_i}} > 0$$

$$d\left(\widetilde{H_M},\tilde{0}\right) = H_M + \frac{\left(\Delta^u_{H_M} - \Delta^l_{H_M}\right)}{4}, \Delta^l_{H_M} > 0 \; and \; \Delta^l_{H_M} > 0$$

$$d\left(\widetilde{H_{R_\iota}},\tilde{0}\right) = H_{R_i} + \frac{\left(\Delta^u_{H_{R_i}} - \Delta^l_{H_{R_i}}\right)}{4}, \Delta^l_{H_{R_i}} > 0 \; and \; \Delta^l_{H_{R_i}} > 0$$

$$d\left(\widetilde{H_{WR_\iota}},\tilde{0}\right) = H_{WR_i} + \frac{\left(\Delta^u_{H_{WR_i}} - \Delta^l_{H_{WR_i}}\right)}{4}, \Delta^l_{H_{WR_i}} > 0 \; and \; ta^l_{H_{WR_i}} > 0$$

$$d\left(\widetilde{H_{DR_\iota}},\tilde{0}\right) = H_{DR_i} + \frac{\left(\Delta^u_{H_{DR_i}} - \Delta^l_{H_{DR_i}}\right)}{4}, \Delta^l_{H_{DR_i}} > 0 \; and \; a^l_{H_{DR_i}} > 0$$

$$d\left(\tilde{\epsilon},\tilde{0}\right) = \epsilon + \frac{\left(\Delta^u_{\epsilon} - \Delta^l_{\epsilon}\right)}{4}, \Delta^l_{\epsilon} > 0 \; and \; \Delta^l_{\epsilon} > 0$$