

Indices	
s	Raw material supplier ,raw_supplier
p	product
i	Raw material supplied ,raw_material
T	Interval time of which the raw material supplied ,time
x	Method used to refurbishment $\forall x$ refurbishment_meth
k	Method used to re design $\forall k$, redesign_method
I	value of inventory inventory
sc	Storage center storage_center
dr	Distribution center distribution_center
ds	Disassembly center disassembly_center
m	Method used of manufacturing manufacture_method
o	Severity class of injury (o,...O) severity(o)

Decision variables	
S_s	Binary variable , if the raw supplier s is selected =1 , otherwise =0, $\forall s$ supplier_selected(raw_supplier)
Y_{Ts}	Binary variable, if the interval selected is a discount interval =1 , otherwise =0, $\forall T, s$ interval_selected (time, raw_supplier, raw_material)
f_x	Binary variable , if the refurbishment method x is selected =1 , otherwise =0, $\forall x$ refurbishment_selected(refurbishment_meth)
G_k	Binary variable , if the redesigning method k is selected =1 , otherwise =0, $\forall k$ redesign_selected(redesign_method)
ps_s	Portion of new product of raw material supplied for each supplier $\forall s$ portion_raw(raw_supplier)
mq_{sip}	Manufacture quantity of raw materials in different intervals , $\forall s, T, p, i$ $manufacture_raw_quantity(time, raw_supplier, raw_material, product)$
Q_s	Capacity of each raw material suppliers , $\forall s$ raw_capacity(raw_supplier)
pc_x	Portion of refurbishment products of each refurbishment method $\forall x$ portion_refurb(refurbishment_meth)
Pf_k	Portion of redesigning products of each redesigning method $\forall k$ portion_redesign(redesign_method)
M_m	Binary variable , if the manufacturing method is used =1 ,otherwise =0, $\forall m$ manufacture_selected(manufacture_method)
SC_{sc}	Binary variable for storage center , if the sc is selected =1 , otherwise =0, $\forall sc$ storage_selected(storage_center)
DR_{dr}	Binary variable for Distribution center , if the dr is selected =1 , otherwise =0 $\forall dr$ distribution_selected(distribution_center)
DC_{ds}	Binary variable for Disassembly center , if the dc is selected =1 , otherwise =0 $\forall ds$ disassembly_selected(disassembly_center)

Parameters	
MP_p	Market price for different products made by raw materials supplied , $\forall p$ market_price (product)
AC_p	Assembly cost of products $\forall p$ assembly_cost (product)
CS_p	cost of shipping the products to the storage centers. $\forall p$ shipping_storage_cost (product)
t_{sc}^p	Transportation cost of shipping the products to the storage centers. . $\forall p, sc$ transp_storage_cost (product, storage_center)
d_{sc}	Distance travelled to the storage centers, $\forall sc$ distance_storage (storage_center)
cd_p	cost of shipping the products to the distribution centers. $\forall p$ shipping_distribution_cost (product)
t_{dr}^p	Transportation cost of shipping the products to the distribution centers . . $\forall p, dr$ transp_distribution_cost (product, distribution_center)
d_{dr}	Distance travelled to the distribution centers , $\forall dr$ distance_distribution (distribution_center)
H_m^p	# of hours needed to made products using raw materials supplied ,for $\forall p, m$ hours_raw (product, manufacture_method)
l	Labor cost per hour . labor_cost
cm_p	Manufacture cost of new products $\forall p$ manufacture_raw_cost (product)
R_s	Variable cost of products made using raw materials supplies $\forall s$ variable_raw_cost (raw_supplier)
Q_s	Capacity of each raw material suppliers , $\forall s$ raw_capacity (raw_supplier)
$\theta_{s,T}$	Manufacture cost of raw materials in different intervals , $\forall s, T$ manufacture_raw_cost (time, raw_supplier, raw_material)
n_i^p	# of each raw material needed to make product p $\forall i, p$ number_raw (raw_material, product)
c_s	Ordering cost from each supplier , $\forall s$ order_raw_cost (raw_supplier)
MP'_p	Market price for different products made by Refurbishment , $\forall p$ market_price_refurb (product)
R_x	Variable cost of products made by Refurbishment method $\forall x$ variable_refurbished_cost (refurbishment_meth)
c_{ds_p}	cost of shipping the products to the disassembly centers.. $\forall p, ds$ shipping_disassembly_cost (product)
t_{ds}^p	Transportation cost of shipping the products to the disassembly centers. . $\forall p, ds$ transp_disassembly_cost (product, disassembly_center)
D_{ds}	Distance travelled to the disassembly centers., $\forall ds$ distance_disassembly (disassembly_center)
df	Defective percentage of returned disassembled products . defective_percentage
h'_p	# of hours needed for Refurbished products $\forall p$ hours_refurbished (product)
cm'_p	Manufacture cost of Refurbished products $\forall p$ manufacture_refurbished_cost (product)
Q_x	Capacity of xth refurbishing methods , $\forall x$ refurbish_method_capacity (refurbishment_meth)
c_x	Ordering Cost of refurbishment method x selected , $\forall x$ order_refurbish_cost (refurbishment_meth)
MP''_p	Market price for different products made by redesigning . $\forall p$ market_price_redesign (product)
h''_p	# of hours needed for redesigning $\forall p$ hours_redesigned (product)

R_k	Variable cost of products made by redesigning method $\forall k$ variable redesigned_cost (redesign_method)
Q_k	Capacity of kth redesigning methods , $\forall k$ redesign_method_capacity (redesign_method)
Cf_k	Ordering Cost of redesigning method k selected , $\forall k$ order_redesign_cost (redesign_method)
Pe	Penalty of excess production penalty_excess
I_0	Initial value of inventory initial_inventory
D	Demand demand
I_f	Final value of inventory final_inventory
invCO	Inventory cost inventory_cost
PDC_p	Pollution of shipping to the disassembly center per unit of distance $\forall p$ pollution_shipping_dissassembly (product)
Ph^p_m	Pollution caused for manufacturing new products using different methods $\forall m, p$ pollution_manufacturing (manufacture_method,product)
PSC_p	Pollution of shipping to the storage center per unit of distance pollution_shipping_storage (product)
Ph'_p	Pollution caused for refurbished $\forall p$ pollution_refurbished (product)
Ph''_p	Pollution caused for redesigning products $\forall p$ pollution_dissassembly (product)
PDR_p	Pollution of shipping to the distribution center per unit of distance $\forall p$ pollution_shipping_distribution (product)
SE^o_m	Severity function for new products for different methods , $\forall m, o$ severity_function_new (manufacture_method,severity)
SE'_o	Severity function of refurbished methods for each severity index , $\forall o$ severity_function_refurbished (severity)
SE''_o	Severity function of redesigning methods for each severity index $\forall o$ severity_function_redesign (severity)
CSC	Capacity of storage centers . capacity_storage
CDR	Capacity of distribution center centers . capacity_distribution
CDS	Capacity of disassembly center centers . capacity_disassembly
A	Returning goal returning_goal
b_d	Uncertain demand uncertain_demand
C^s_T	upper bound of the discount interval T offered by supplier s , $\forall T, s$ up_bound (time, raw_supplier, raw_material)
C^T_s	slightly smaller than C^s_T . $\forall T, s$ bound (time, raw_supplier, raw_material)

Deterministic model:

$$\begin{aligned}
F1 = \text{MAX} \quad & \sum_{\text{raw_supplier}} \left(\sum_{\text{product}} \left(\text{market_price}(\text{product}) - \text{assembly_cost}(\text{product}) \right. \right. \\
& - \sum_{\text{storage_center}} \left((\text{shipping_storage_cost}(\text{product}) + \text{transp_storage_cost}(\text{product}, \text{storage_center})) \right. \\
& \left. \left. * \text{distance_storage}(\text{storage_center}) \right) * \text{storage_selected}(\text{storage_center}) \right) \\
& - \sum_{\text{distribution_center}} \left((\text{shipping_distribution_cost}(\text{product})) + \text{transp_distribution_cost}(\text{product}, \text{distribution_center}) \right. \\
& \left. \left. * \text{distance_distribution}(\text{distribution_center}) \right) * \text{distribution_selected}(\text{distribution_center}) \right) \\
& - \sum_{\text{manufacture_method}} \left(\text{hours_raw}(\text{product}, \text{manufacture_method}) * \text{labor_cost} \right) * \text{manufacture_selected}(\text{manufacture_method}) \\
& - \text{manufacture_raw_cost}(\text{product}) - \text{variable_raw_cost}(\text{raw_supplier}) \\
& * \left(\sum_T \left(\sum_i \left(\sum_{\text{product}} \left(\text{manufacture_raw_quantity}(\text{time}, \text{raw_supplier}, \text{raw_material}, \text{product}) \right. \right. \right. \right. \\
& \left. \left. \left. / \text{number_raw}(\text{raw_material}, \text{product}) \right) * \text{interval_selected}(\text{time}, \text{raw_supplier}, \text{raw_material}) \right) \right) \\
& \left. * \text{portion_raw}(\text{raw_supplier}) \right) \\
& - \sum_{\text{raw_supplier}} \text{order_raw_cost}(\text{raw_supplier}) * \text{supplier_selected}(\text{raw_supplier}) \\
& - \sum_{\text{refurbishment_meth}} \left(\sum_{\text{product}} \left(\text{market_price_refurb}(\text{product}) - \text{assembly_cost}(\text{product}) \right. \right. \\
& - \text{variable_refurbished_cost}(\text{refurbishment_meth}) - \sum_{\text{storage_center}} \left((\text{shipping_storage_cost}(\text{product}) \right. \\
& \left. + \text{transp_storage_cost}(\text{product}, \text{storage_center}) * \text{distance_storage}(\text{storage_center})) \right. \\
& \left. \left. * \text{storage_selected}(\text{storage_center}) \right) - \sum_{\text{distribution_center}} \left((\text{shipping_distribution_cost}(\text{product}) \right. \right. \\
& \left. \left. + \text{transp_distribution_cost}(\text{product}, \text{distribution_center}) * \text{distance_distribution}(\text{distribution_center})) \right. \right. \\
& \left. \left. * \text{distribution_selected}(\text{distribution_center}) \right) - \sum_{\text{disassembly_center}} \left((\text{shipping_disassembly_cost}(\text{product}) \right. \right. \\
& \left. \left. + \text{transp_disassembly_cost}(\text{product}, \text{disassembly_center}) * \text{distance_disassembly}(\text{disassembly_center})) \right. \right. \\
& \left. \left. * \text{disassembly_selected}(\text{disassembly_center}) \right) + \text{defective_percentage} / (1 - \text{defective_percentage}) \right. \\
& \left. * \sum_{\text{disassembly_center}} \left((\text{shipping_disassembly_cost}(\text{product}) \right. \right. \\
& \left. \left. + \text{transp_disassembly_cost}(\text{product}, \text{disassembly_center}) * \text{distance_disassembly}(\text{disassembly_center})) \right. \right. \\
& \left. \left. * \text{disassembly_selected}(\text{disassembly_center}) \right) - (\text{hours_refurbished}(\text{product}) * \text{labor_cost}) \right. \\
& \left. - \text{manufacture_refurbished_cost}(\text{product}) \right) * ((1 - \text{defective_percentage}) \\
& * \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment_meth})) \\
& - \sum_{\text{refurbishment_meth}} \left(\text{order_refurbish_cost}(\text{refurbishment_meth}) \right. \\
& \left. * \text{refurbishment_selected}(\text{refurbishment_meth}) \right) \\
& + \sum_{\text{redesign_method}} \left(\sum_{\text{product}} \left(\text{market_price_redesign}(\text{product}) \right. \right. \\
& - \sum_{\text{distribution_center}} \left((\text{shipping_distribution_cost}(\text{product}) \right. \\
& \left. + \text{transp_distribution_cost}(\text{product}, \text{distribution_center}) * 2 * \text{distance_travelled}(\text{distribution_center})) \right. \\
& \left. \left. * \text{distribution_selected}(\text{distribution_center}) \right) - (\text{hours_redesigned}(\text{product}) * \text{labor_cost}) \right) \\
& - \text{variable_refurbished_cost}(\text{redesign_method}) * (\text{portion_redesign}(\text{redesign_method}) \\
& * \text{redesign_method_capacity}(\text{redesign_method})) \\
& - \sum_{\text{redesign_method}} \left(\text{order_redesign_cost}(\text{redesign_method}) * \text{redesign_selected}(\text{redesign_method}) \right) \\
& - \text{penalty_excess} * (\text{initial_inventory} \\
& + \sum_{\text{raw_supplier}} (\text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier})) + ((1 - \text{defective_percentage})
\end{aligned}$$

$$\begin{aligned}
& * \sum_{\text{refurbishment_meth}} (\text{portion_refurb}(\text{refurbishment_meth}) \\
& * \text{refurbish_method_capacity}(\text{refurbishment_meth})) \\
& + \sum_{\text{redesign_method}} (\text{portion_redesign}(\text{redesign_method}) * \text{redesign_method_capacity}(\text{redesign_method})) \\
& - \text{demand} - \text{final_inventory}) - \text{inventory_cost} * \text{final_inventory}
\end{aligned}$$

$$\begin{aligned}
F2 = \text{MIN} \bigg(& \sum_{\text{raw_supplier}} \left(\sum_{\text{product}} \left(\sum_{\text{storage_center}} (\text{pollution_}(\text{shipping_storage}(\text{product}) * \text{storage_selected}(\text{storage_center}) \right. \right. \\
& * \text{distance_storage}(\text{storage_center})) + \sum_{\text{distribution_center}} (\text{pollution_}(\text{shipping_distribution}(\text{product}) \\
& * \text{distance_travelled}(\text{distribution_center}) * \text{distribution_selected}(\text{distribution_center}))) \\
& * \text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier})) \\
& + \sum_{\text{refurbishment_meth}} \left(\sum_{\text{product}} \left(\sum_{\text{storage_center}} (\text{pollution_}(\text{shipping_storage}(\text{product}) \right. \right. \\
& * \text{distance_storage}(\text{storage_center}) * \text{storage_selected}(\text{storage_center})) \\
& + \sum_{\text{distribution_center}} (\text{pollution_}(\text{shipping_distribution}(\text{product}) \\
& * \text{distance_distribution}(\text{distribution_center}) * \text{distribution_selected}(\text{distribution_center})) \\
& + \sum_{\text{disassembly_center}} (\text{pollution_}(\text{shipping_dissassembly}(\text{product}) \\
& * \text{distance_disassembly}(\text{disassembly_center}) * \text{disassembly_selected}(\text{disassembly_center})) \\
& - \text{defective_percentage} / (1 - \text{defective_percentage}) \\
& * \sum_{\text{disassembly_center}} (\text{pollution_}(\text{shipping_dissassembly}(\text{product}) \\
& * \text{distance_disassembly}(\text{disassembly_center}) * \text{disassembly_selected}(\text{disassembly_center}))) * ((1 \\
& - \text{defective_percentage}) * \text{portion_refurb}(\text{refurbishment_meth}) \\
& * \text{refurbish_method_capacity}(\text{refurbishment_meth})) \\
& + \sum_{\text{redesign_method}} \left(\sum_{\text{product}} \left(\sum_{\text{distribution_center}} (\text{pollution_}(\text{shipping_distribution}(\text{product}) * 2 \right. \right. \\
& * \text{distance_travelled}(\text{distribution_center}) * \text{distribution_selected}(\text{distribution_center}))) \\
& * (\text{portion_redesign}(\text{redesign_method}) * \text{redesign_method_capacity}(\text{redesign_method})) \bigg) \\
& + \sum_{\text{raw_supplier}} \left(\sum_{\text{product}} \left(\sum_{\text{manufacture_method}} (\text{pollution_}(\text{manufacturing}(\text{manufacture_method}, \text{product}) \right. \right. \\
& * \text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier}) \\
& * \text{manufacture_selected}(\text{manufacture_method})) \\
& + \sum_{\text{refurbishment_meth}} \left(\sum_{\text{product}} \text{pollution_}(\text{refurbished}(\text{product}) * \text{portion_refurb}(\text{refurbishment_meth}) \right. \\
& * \text{refurbish_method_capacity}(\text{refurbishment})) \\
& + \sum_{\text{redesign_method}} \left(\sum_{\text{product}} \text{pollution_}(\text{dissassembly}(\text{product}) * \text{portion_redesign}(\text{redesign_method}) \right. \\
& * \text{redesign_method_capacity}(\text{redesign_method})) \bigg)
\end{aligned}$$

$$\begin{aligned}
& f3 \\
& = \sum_{o=1}^o \sum_{\text{manufacture_method}} (\text{manufacture_selected}(\text{manufacture_method}) * e^{o-\Sigma_0^o} * \text{Severity_function_new}(\text{manufacture_method}, \text{severity}) \\
& * \sum_{\text{raw_supplier}} \sum_{\text{product}} \frac{20000}{\text{hours_raw}(\text{product}, \text{manufacture_method}) * \text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier})} + \sum_{o=1}^o e^{o-\Sigma_0^o} \\
& * \text{severity_}(\text{function_refurbished}(\text{severity})) \\
& * \sum_{\text{refurbishment_meth}} \sum_{\text{product}} \frac{20000}{\text{hours_refurbished}(\text{product}) * (1 - df) * \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment_meth})} \\
& + \sum_{o=1}^o e^{o-\Sigma_0^o} \text{severity_}(\text{function_redesign}(\text{severity})) \\
& * \sum_{\text{redesign_method}} \sum_{\text{product}} \frac{20000}{\text{hours_redesigned}(\text{product}) * \text{portion_redesign}(\text{redesign_method}) * \text{redesign_method_capacity}(\text{redesign_method})}
\end{aligned}$$

S.T

$$\begin{aligned}
\text{raw_capacity}(\text{raw_supplier}) &= (\sum_T \sum_i \sum_{\text{product}} (\text{manufacture_raw_quantity}(\text{time}, \text{raw_supplier}, \text{raw_material}, \text{product})) / \\
&\text{number_raw}(\text{raw_material}, \text{product}) / \text{number_raw}(\text{raw_material}, \text{product})) \quad \forall \text{raw_supplier}, \text{time}, \text{raw_material} \\
&\text{raw_capacity}(\text{raw_supplier}) \\
&\leq \text{up_bound}(\text{time}, \text{raw_supplier}, \text{raw_material}) / \text{number_raw}(\text{raw_material}, \text{product}) \\
&* \text{interval_selected}(\text{time}, \text{raw_supplier}, \text{raw_material}) \quad \forall \text{raw_supplier}, \text{time}, \text{raw_material} \\
&\text{raw_capacity}(\text{raw_supplier}) \\
&\geq \text{bound}(\text{time} - 1, \text{raw_supplier}, \text{raw_material}) / \text{number_raw}(\text{raw_material}, \text{product}) \\
&* \text{interval_selected}(\text{time}, \text{raw_supplier}, \text{raw_material}) \quad \forall \text{raw_supplier}, \text{time}, \text{raw_material}
\end{aligned}$$

$$\text{interval_selected}(\text{time}, \text{raw_supplier}, \text{raw_material}) = 1 \text{ if selected, otherwise } = 0$$

$$\sum_{\text{raw_supplier}} \sum_{\text{time}} \text{interval_selected}(\text{time}, \text{raw_supplier}) \leq 1 \quad \forall \text{raw_supplier}, \text{time}$$

$$\begin{aligned}
\text{capacity_storage} &\geq \sum_{\text{raw_supplier}} \text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier}) + (1 \\
&- \text{defective_percentage}) \sum_{\text{refurbishment_meth}} \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment}
\end{aligned}$$

$$\begin{aligned}
\text{capacity_distribution} &\geq \sum_{\text{raw_supplier}} \text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier}) + (1 - \text{defective_percentage}) \\
&* \sum_{\text{refurbishment_meth}} \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment} \\
&+ \sum_{\text{redesign_method}} \text{portion_redesign}(\text{redesign_method}) * \text{redesign_method_capacity}(\text{redesign_method})
\end{aligned}$$

$$\text{capacity_disassembly} \geq \sum_{\text{refurbishment_meth}} \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment_meth})$$

$$\text{portion_raw}(\text{raw_supplier}) \leq \text{supplier_selected}(\text{raw_supplier}), \forall \text{ raw_supplier}$$

$$\text{portion_refurb}(\text{refurbishment_meth}) \leq \text{refurbishment_selected}(\text{refurbishment_meth}), \forall \text{ refurbishment_meth}$$

$$\begin{aligned} \text{portion_redesign}(\text{redesign_method}) &\leq \text{redesign_selected}(\text{redesign_method}) \\ &\forall \text{ redesign_method} \end{aligned}$$

$$\begin{aligned} \text{initial_inventory} + &\sum_{\text{raw_supplier}} \text{portion_raw}(\text{raw_supplier}) * \text{raw_capacity}(\text{raw_supplier}) + (1 - \text{defective_percentage}) \\ &* \sum_{\text{refurbishment_meth}} \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment_meth}) \\ &+ \sum_{\text{redesign_method}} \text{portion_redesign}(\text{redesign_method}) * \text{redesign_method_capacity}(\text{redesign_method}) - \text{final_inventory} \geq \text{demand} \end{aligned}$$

$$\begin{aligned} (1 - \text{defective_percentage}) & * \sum_{\text{refurbishment_meth}} \text{portion_refurb}(\text{refurbishment_meth}) * \text{refurbish_method_capacity}(\text{refurbishment_meth}) \\ & + \sum_{\text{redesign_method}} \text{portion_redesign}(\text{redesign_method}) * \text{redesign_method_capacity}(\text{redesign_method}) \geq \text{returning_goal} * \text{demand} \end{aligned}$$

$$\text{defective_percentage} \leq 1$$

$$\begin{aligned} \text{portion_raw}(\text{raw_supplier}), \text{portion_refurb}(\text{refurbishment_meth}), \text{portion_redesign}(\text{redesign_method}) \\ \geq 0, \forall \text{ raw_supplier}, \text{refurbishment_meth}, \text{redesign_method} \end{aligned}$$

$$\begin{aligned} \text{supplier_selected}(\text{raw_supplier}), \text{refurbishment_selected}(\text{refurbishment_meth}), \text{redesign_selected}(\text{redesign_method}) \\ , \text{manufacture_selected}(\text{manufacture_method}), \in \{0,1\} \end{aligned}$$

Multiple objectives will be solved by the **weighted sum model**

$$\max w_1 \theta_1 F_1 - w_2 \theta_2 F_2 - w_3 \theta_3 F_3$$

$$w_i \geq 0, \forall i$$

$$\sum_0^{i=3} w_i = 1$$