An Integrated Multi-Echelon Stochastic Supply Chain Production-Distribution Model With Carbon Emissions

By

Rishabh Ranka, Biswajita Mohanty, Manidhar Darisi Venkata, Raj Kumar Singh, Pavan Kumar Kulkarni

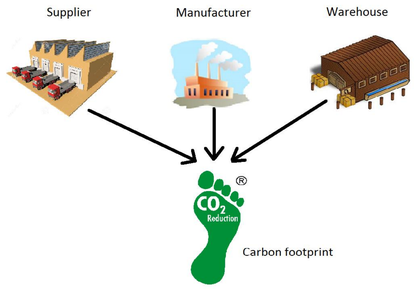
Under the guidance of

Dr. Vijayakumar Manupati

School of Mechanical and Building Sciences

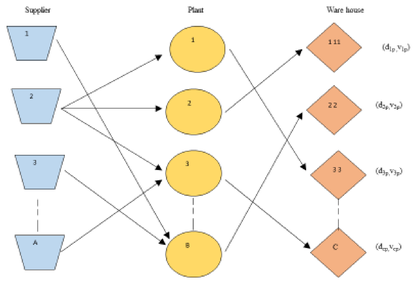
Vellore Institute Of Technology, Vellore, Tamil Nadu-632014 India.

Graphical Abstract



Problem definition

Problem Description



Assumptions -

1) It is assumed that the lead time from plant *B* to item *I* is a constant parameter.

2) The value of standard normal distribution is assumed to be fixed for the entire network.

3) It is assumed that no capacity constraint limits the order quantity.

4) All demands are satisfied.

5) Setup times are included on the assembly times and item shortage to assemble of the final product never occurs.

6) Each facility B *(B*∈ *M)* manages a unique output product (which may be an intermediate or a final product), one unit of which is possibly obtained from multiple units of different input products). Thus, to each facility *B* corresponds a set of unit products and a unique output product.

7) Each facility *B (B*∈ *M* ∪ *R)* has only one upstream node for each input product. Note that facility *B* may have several upstream nodes, which may be external suppliers or other manufacturing facilities. An external supplier may provide facility *B* with several products.

Mathematical Formulation

Min Z=

$$Z_1 = Min\sum_B \sum_B F_B X_B + PH\sum_C \sum_B \sum_P TC_{CBP} * \mu_{CB} * Y_{CBP} + PH\sum_B \sum_A \sum_I \overline{TC_{BAI}} * D_{BI} * Z_{BAI} + PH\sum_B \sum_I \sqrt{2HC_{BI} * OC_{BI}} * \sqrt{D_{BI}} + PH\sum_B \sum_I HC_{BI} * Z_{1-\alpha} \sqrt{LT_{BI}} * \sqrt{V_{BI}} + \sum_C \sum_B \sum_P \sum_t \left[REX_{CBPT} * C_{BPT} + OVX^1_{CBPT} * C^1_{BPT}\right] + \sum_C \sum_P \sum_t \ln_{CPT} * Whc_{CP} \quad (1)$$

$$Z_2 = \sum_{t=1}^{T} \sum_{P\in\phi} \left(EOF^t_{PB} b^t_{PB} + EOV^t_{PB} X^t_{PB}\right) + \sum_{t=1}^{T} \left[EMF^t_B a^t_B + EMV^t_B \left(X^t_B + S^t_B\right)\right] + \sum_{t=1}^{T} \sum_{P\in\phi} EI^t_{PB} \frac{h^t_{PB} + h^{t+1}_{PI}}{2} \quad (2)$$

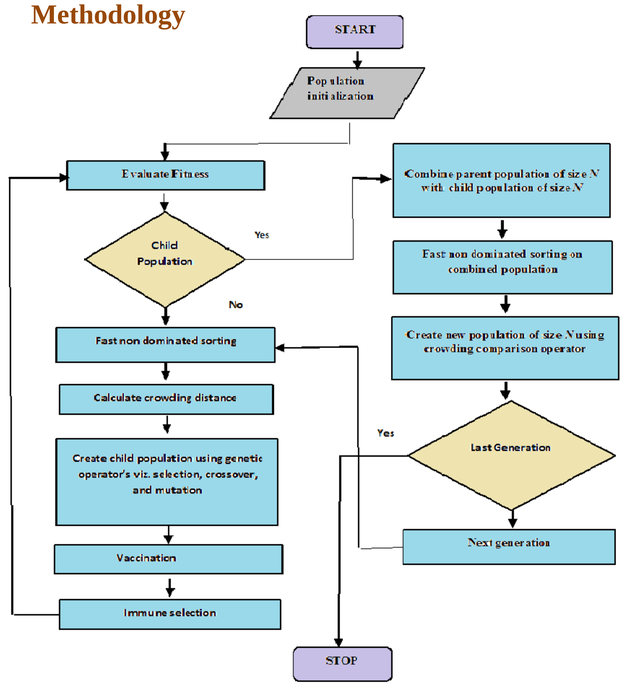


Fig 2 . Flowchart of AI-NSGA 2

Subject to Constraints -

$$\sum_B Y_{CBP} = 1 \ \forall C = 1,\ldots,C \ \forall P = 1,\ldots,P \quad (3)$$

$$\sum_A Z_{BAI} = X_B \ \forall I = 1,\ldots,I \ \forall B = 1,\ldots,B \quad (4)$$

$$\sum_A \sum_I D_{BI} * S_I * Z_{BAI} \le Cap^2_B * X_B \ \forall B = 1,\ldots,B \quad (5)$$

$$\sum_C \mu_{CP} * q_P * Y_{CBP} \le Cap^1_{BP} * X_B \ \forall B = 1,\ldots,B \ \forall P = 1,\ldots,P \quad (6)$$

$$\sum_C \sum_P \mu_{CP} * Y_{CBP} * b_{PI} = D_{BI} \ \forall B = 1,\ldots,B \ \forall I = 1,\ldots,I \quad (7)$$

$$\sum_C \sum_P \sigma_{CP} * Y_{CBP} * b^2_{PI} = V_{BI} \ \forall B = 1,\ldots,B \ \forall I = 1,\ldots,I \quad (8)$$

$$X_B, Y_{CBP}, Z_{BAI} \in \{0,1\} \ \forall I = 1,\ldots,I \ \forall C = 1,\ldots,C \ \forall P = 1,\ldots,P \ \forall B = 1,\ldots,B \ \forall A = 1,\ldots,A \quad (9)$$

$$\ln_{CP,t-1} + REX_{CPBT} - \ln_{CPT} \ \forall i, j, I, t = \forall C, B, P, t \quad (10)$$

$$\sum_C \sum_P REX_{CBP} * q_P \le Tr_{Bt} \ \forall B \quad (11)$$

$$\sum_C \sum_P OVX^1_{CBP} * q_P \le To_{Bt} \ \forall B \quad (12)$$

$$\sum_P \ln_{CPt} * u_P \le Cap^3_C \ \forall C, \ t \quad (13)$$

$$\sum_t \left[REX_{CBPT} + OVX^1_{CBPT}\right] \le Y_{CBP} * M \ \forall C, B, P \quad (14)$$

$$REX_{CBPT}, OVX^1_{CBPT} \ge 0 \ \forall C, B, P, t \quad (15)$$

MATLAB CODE (AI-NSGA-II)

```
clear all
clc;
pop_size=100;
chrom_len=12;
pop= randint(pop_size,chrom_len);
pop1=[];
pop2=[];
pop3=[];
pop4=[];
pop5=[];
pop6=[];
xu=10;
xl=0;
pc=0.8;
pm=0.1;
 b=zeros(pop_size,1);
fcum =zeros(pop_size,1);
ysum=0;ysum1=0;
   dv= zeros(pop_size,1);
   dv1= zeros(pop_size,1);

  for gen=1:100

for i=1:pop_size
   for j=1:chrom_len
     dv(i,1) = dv(i,1)+(pop(i,j)*2^(chrom_len-j));
   end
end
for i= 1:pop_size
  x(i,1)= xl + (((xu-xl)/((2^chrom_len)-1))*dv(i,1));
  y(i,1)=x(i,1)*sin(x(i,1)) ;
   ysum= ysum + y(i,1);
end
for i=1:pop_size
  f(i,1)=y(i,1)/ysum;
  fcum(i+1,1) = fcum(i,1)+f(i,1);
   fcum(i,1)=fcum(i+1,1);
end
%%%%selection%%%%%%%%%%%%%%
for i=1:pop_size
   a=rand;
   if (a<fcum(1,1))
   b(i,1)=1;
   else
   for j=1:pop_size
      if(a>fcum(j,1)&& a<fcum(j+1,1))
      b(i,1)=j+1;
      end
   end
end
end
for i=1:pop_size
   for j=1:chrom_len
     pop1(i,j)=pop(b(i),j);
   end
end
j=1;
for i=1:pop_size
   a=rand;
   if(a<pc)
      pop2(j,:)=pop1(i,:);
      c(j)=i;
      j=j+1;
   end
end
```

```
%%%%%%%%%crossover%%%%%%%%%
k=0;
v=pop(j+1,:);
new_pop(i,:)=v;

for i=1:10
  rb(i)=rand(1);
  if (rb(i)<pc)
    z(i)=1;
    k=k+1;
    par_pop(k,:)=new_pop(i,:);
  else
    z(i)=0;
  end
end
child1=[par_pop(1,1:cpoint) par_pop(2,cpoint+1:chrom_len)];

child2=[par_pop(2,1:cpoint) par_pop(1,cpoint+1:chrom_len)];
[m,n]=size(z);
lat_pop=new_pop;
for i=1:n
if (z(:,i)==1)
  d=i;
  lat_pop(d,:)=child1;
 break;
end
end
x=d+1;
for i=x:n
if(z(:,i)==1)
  lat_pop(i,:)=child2;
  break;
end
end
```

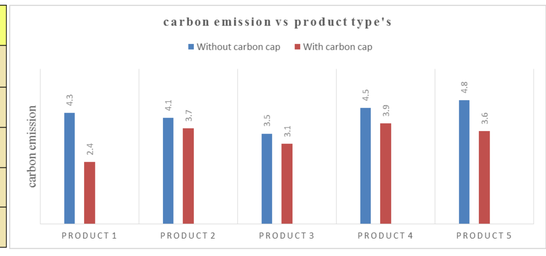
```
%%%%%%%%%%%%%%%%%%%%Mutation%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
pm=0.01;
m=12;
total_bit=m*pop_size;
b=rand(1,total_bit);
mpoint=randi(chrom_len-1);
c=0;
for i=1:total_bit
if (b(:,i)<pm)
  w(i)=1;
  c=c+1;
  par_mut(c,:)=lat_pop((ceil(i/12)),:);
  [m,n]=size(par_mut);
%   bit=par_mut(:,mpoint);
%   bit1=circshift(bit,1);
    bit=1;
  new_child(c,:)=[par_mut(c,1:mpoint-1) par_mut(c,bit) par_mut(c,mpoint+1:chrom_len)];
else
  w(i)=0;
end
end
fx=lat_pop;
   for i=1:120
     if (w(i)==1)
       B=i;
       e=ceil(B/12);
       fx(e,:)=new_child(1,:);
       break;
     end
   end
 ysum=0;ysum1=0;
  dv= zeros(pop_size,1);
  dv1= zeros(pop_size,1);

for i=1:pop_size
  for j=1:chrom_len
    dv(i,1) = dv(i,1)+(pop(i,j)*2^(chrom_len-j));
  end
end
for i= 1:pop_size
  x(i,1)= xl + (((xu-xl)/((2^chrom_len)-1))*dv(i,1));
  y(i,1)=x(i,1)*sin(x(i,1)) ;
   ysum= ysum + y(i,1);
end

   end
```

Computational results

Products	TC_{CBP}	TC_{BAI}	FC	HC	OC	C_{BPt}	C^1_{BPt}	Whc_{CP}
P1	846.25	663.91	1556.67	69	330	236	319	0.57
P2	824.69	643.34	1492.39	70	282	342	218	0.89
P3	803.79	623.56	1396.63	84	251	396	396	1.2
P4	794.78	617.66	1329.63	63	346	219	262	1.46
P5	773.01	608.45	1264.07	78	299	343	327	0.97



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