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An integrated model for optimizing distribution network with considering assembly line balancing

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Abstract

In this research, we consider production planning, assembly line balancing, and supply chain optimization coordinately. Producers determine their production plan for the aim of manufacturing the components. Then they send their productions to assemblies and after those assemblies assemble those pieces to make the final product and send them to final customers. Also the assemblies need to balance the assembly line. After introducing our model, an example is shown which our model has been implemented on a set of data to indicate the capability of our model.

Keywords: Assembly line balancing, Supply chain optimization, manufacturing programming, optimizing distribution network

Introduction:

The word "Supply chain management" (SCM), introduced in 80 decade, and it was widely used in the late of 90 decade. At first we define some useful definition in the field of supply chain management:

- Coordination of the systematic and strategic function of the business, and tactics between these functions in a company with the other business existing in the supply chain (Dong et al, 2009).
- Supply chain management is coordination in production, stock, inventory, location, and transportation between companies in a supply chain to achieve the best structure of responsiveness and efficiency in the matter of being successful in the market (Christopher and towill, 2002).
- Supply chain management is integrating some activities and related information flow (Khorasani, 2014), with the aid of improvement and coordination of activities in production supply chain (Agarwel et al, 2007).

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Designing and optimizing the supply chain distribution is a suitable field to study. Therefore a lot of mathematical and methahuristic models has been offered, considering assumption below: (Paksoy, 2012)

- Location of the facilities (plants, center distribution, …)
- Designing configuration networks
- Estimating demand of the customer with the aim of minimizing total cost. (Purchase cost, transportation cost and fixed operational cost.

Balancing assembly line is a midterm tactical decision in the management of production system. (School&bik, 2006)

Fail to balance the assembly line leads to increase the cycle time and idle time and consequently it leads to decrease rate of production, efficiency of the line and increasing the total system costs. All of these factors are directly impressive to reduce the rate of productivity. Most of the researchs in this field are concentrated on two kind of line balancing. The first type, the cycle time of the line is specified and we should minimize number of work stations. In the second type the assembly stations are specified and we must minimize the total cycle time.

Paksoy et al, in 2012 searched supply chain optimization problem and balancing assembly line simultaneously. They introduced a non-linear and integer mathematical model in their research with the aim of minimizing total cost and work stations. Shahpoori et al in 2013 introduced a multi-choice model for supply chain network. Also Iren et al in 2014 concentrated on modeling and optimizing the integration of designing closed-loop supply chain and balancing assembly line. According to these researches, we cannot observe an integrated multi-choice model which considers decision for supply chain, balancing assembly line, and production planning simultaneously. So we survey in this context in our research.

Problem definition:

In this research, we consider production planning, balancing assembly line and optimization supply chain simultaneously. In this model, producers specify their production plan. Then they send their production to be assembled. After this assembly process, the final product is ready to be sailed. So the assembly line should be balanced.

Required signs, parameters and decision variable in this model are:

M: sign of producers $m = 1,2,3, \dots, M$

A: sign of person who assemble $a = 1,2,3, \dots, A$

C: sign of customers $c = 1,2,3, \dots, C$

P: sign of time period $p = 1,2,3, \dots, P$

K: sign of components $k = 1,2,3, \dots, K$

J: sign of work stations $j = 1,2,3, \dots, J$

I: sign of assembly department task $i = 1,2,3, \dots, I$

R: Sign of production resources $r = 1,2,3, \dots, R$

$Predec_i$: Precedent set for "i"th task

Tpp: Set of duties which must be placed in one work station

Tnp: Set of duties which must not be placed in one work station

T_i: Required time for "i"th task

W_p: Total available working time to assemble in "p"th period

B_{ap}: Capacity of assembly "a" in period "p"
U_{cp}: Demand of customer "c" in period "p"
C_{map}: Cost of sending stuff from producer "m" to assembly "a" in period "p"
C_{acp}: Cost of sending stuff from assembly "a" to customer "c" in period "p"
O: Cost of adding one work station
D_{ma}: distance between producer "m" and assembly "a"
D_{ac}: distance between assembly "a" and customer "c"
POH_{mk}: Inventory on hand of producer "m" from component "k" in first period
C_{mr}: Capacity of resource "r" for producer "m" in first period
A_{rk}: Capacity to be used from resource "r" to produce unit of component "k"
C_k^p: Cost of producing unit of component "k" in period "p"
C_k^h: Cost of keeping unit of component "k" in period "p"
U_r^p: Cost of supplying unit of resource "r" in period "p"
H_{rp}: cost of keeping unit of resource "r" in period "p"

Decision variable are as follow:
X_{makp}: Amount of sent component "k" from producer "m" to assembly "a" in period "p"
Y_{acp}: Amount of sent final product from assembly "a" to customer "c" in period "p"
CT_{ap}: Cycle time for assembly "a" in period "p"
V_{aijp}: Binary variable, $\begin{cases}\text{assign 1 if for assembly "a", task "i" to station "j" in period "p" is assigned}\\ \text{Assign 0 otherwise}\end{cases}$
Z_{ajp}: Binary variable, $\begin{cases}\text{assign 1 if for assembly "a" a task in "j"th station is assigned}\\ \text{Assign 0 otherwise}\end{cases}$

I_{mkp}: level of the primary inventory for component "k" for producer "m" in period "p"
X_{mkp}: Amount of produced component "k" by producer "m" in period "p"
F_{mkp}: Level of final component "k" for producer "m" in period "p"
C_{mrp}: Amount of resource "r" should be supplied by producer "m" in period "p"
S_{mrp}: Extra units of resource "r" from producer "m" which is useless in period "p"
ALL_{mkp}: Average level of inventory "k" for producer "m" in period "p"

The objective function can be shown as:

$$\min z = \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{p=1}^{P}(x_{mkp}.c_k^p + AIL_{mkp}.c_k^h + c_{mrp}.u_{rp} + s_{mrp}.h_{rp}) + \sum_{m=1}^{M}\sum_{a=1}^{A}\sum_{k=1}^{K}\sum_{p=1}^{P} x_{makp}.d_{ma}.c_{map} + \sum_{a=1}^{A}\sum_{c=1}^{C}\sum_{p=1}^{P} y_{acp}.d_{ac}.c_{acp} + \sum_{a=1}^{A}\sum_{j=1}^{J}\sum_{p=1}^{P} Z_{ajp}.o$$

Cost of production, keeping inventory, supply and shortage of resources is shown in first part. Cost of sending components between assembly and producers is in second part. In third part shows cost of sending final product between assembly and producers. And last part shows cost of adding work stations.

Constraints of model are as follow:

- Constraint of inventory

$$i_{mk1} = POH_{mk} \; \forall k, m$$
$$i_{mkp} = f_{mk(p-1)} \; \forall k, m, p \neq 1$$
$$AIL_{mkp} = \frac{f_{mk(p-1)} + f_{mkp}}{2} \;\; \forall k, m, p$$

- Constraints of demand

$$x_{mkp} + f_{mk(p-1)} - f_{mkp} = \sum_{a=1}^{A} x_{makp} \;\; \forall m, k, p \neq 1$$
$$x_{mk1} + POH_{mk} - f_{mk1} = \sum_{a=1}^{A} x_{mak1} \;\; \forall m, k$$

- Constraints of resources

$$\sum_{k=1}^{K} a_{rk}.x_{mkp} - s_{mrp} = c_{mrp} - s_{mr(p-1)} \;\; \forall m, r, p$$

- Number of products sent from assembly to all customer are less than the capacity of assembly:

$$\sum_{c=1}^{C} y_{acp} \leq b_{ap} \;\; \forall a, p$$

- Demand of customer will be estimated by assembly:

$$\sum_{a=1}^{A} y_{acp} \geq u_{cp} \;\; \forall c, p$$

- Set of products, sent by all producers to each assembly in each period is equal to set of products, sent by each assembly to all customers:

$$\sum_{m=1}^{M} x_{makp} = \sum_{c=1}^{C} y_{acp} \;\; \forall a, k, p$$

- For each assembly in each period, each task should be assigned to a work station:

$$\sum_{j=1}^{J} v_{aijp} = 1 \;\; \forall a, i, p$$

- Task "r" is precedent to task "s":

$$\sum_{j=1}^{J} j * v_{arjp} \leq \sum_{j=1}^{J} j * v_{asjp} \quad \forall r, s \in Predec_i$$

$$\sum_{i=1}^{N} v_{aijp} \leq J.Z_{ajp} \ \forall a, p, j$$

- Cycle time:

$$CT_{ap} = \frac{w_p}{\sum_{c=1}^{C} y_{acp}} \quad \forall a, p$$

- Summations of the required time for the task which has been assigned to a work station, must be less than cycle time:

$$\sum_{i=1}^{I} t_i.v_{aijp} \leq CT_{ap} \ \forall a, p, j$$

- Tasks which must be assigned to a work station:

$$v_{asjp} = v_{arjp} \ \forall a, p, j \quad \forall s, j \in tpp$$

- Tasks which must not be assigned to a work station:

$$v_{asjp} + v_{arjp} \leq 1 \ \forall a, p, j \quad \forall s, j \in tnp$$

- And:

$$x_{makp}, y_{acp}, CT_{ap}, x_{mkp}, i_{mkp}, f_{mkp}, c_{mrp}, s_{mrp}, AIL_{mkp} \geq 0$$
$$v_{aijp}, z_{ajp} \in \{0,1\}$$

Numerical example

The data, given for the problem are as follow:

$w_p = 28800min, M = 4, C = 4, A = 2, P = 2, K = 7, I = 8, J = 6, r = 2$

And reminders are as:

Table 1: The data given for the problem

	1	2	3	4	5	6	7	8
c_k^p	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
c_k^h	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
a_{1k}	2	2	2	2	2	2	2	2
a_{2k}	3	3	3	3	3	3	3	3

Table 2: Component capacities of manufacturers during any period

	*M*1		*M*2		*M*3		*M*4	
Components	*P*1	*P*2	*P*1	*P*2	*P*1	*P*2	*P*1	*P*2
1	7000	7000	7200	7200	6700	6700	6500	6500
2	7000	7000	7200	7200	6700	6700	6500	6500
3	7000	7000	7200	7200	6700	6700	6500	6500
4	7000	7000	7200	7200	6700	6700	6500	6500
5	7000	7000	7200	7200	6700	6700	6500	6500
6	7000	7000	7200	7200	6700	6700	6500	6500
7	7000	7000	7200	7200	6700	6700	6500	6500

Table 3: Capacities of assemblers and demand of customers during ant period

P	*A*1	*A*2	*C*1	*C*2	*C*3	*C*4
1	4200	6900	1360	1440	1360	1360
2	4300	6100	1360	1280	1520	1200

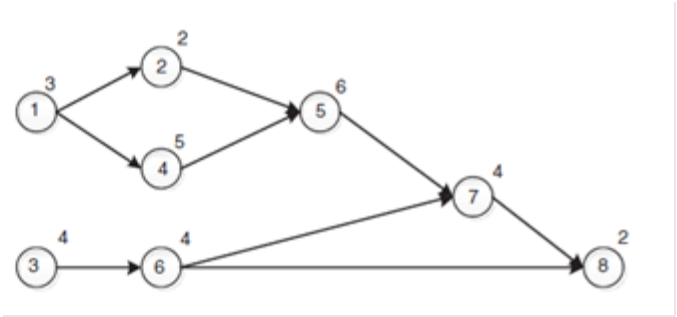

Fig.1: Flow diagram for the example

Material or other resources purchase costs are as follow:
$u_{1p} = 0.3, u_{2p} = 0.2$
Cost of keeping each unit of the extra material in each period will be 0.3 monetary units. And the other information is:
$POH_{mk} = 300, c_{mr} = 4, o = 0.3$

Now we want to solve this model and we use Gams software for this purpose. Results are as follow:

Table 4: Amount of sent product from each producer to each assembly in first period

Component7	Component6	Component5	Component4	Component3	Component2	Component 1	Assemblies	Producers
2430.952	2430.952	2430.952	2430.952	2430.952	2430.952	2430.952	Assembly 1	Producer 3
0	0	50	0	1517.619	3039.048	0	Assembly 2	Producer 1
3089.048	3089.048	3089.048	3089.048	1571.429	50	3089.048	Assembly2	Producer4

Table 5: Amount of product, sent from each producer to each assembly in second period

Component 7	Component 6	Component 5	Component 4	Component 3	Component 2	Component 1	Assemblies	Producers
2560	2560	2560	2560	2560	2560	2560	1	1
2800	216.667	2800	2800	2800	2800	2800	2	2
0	2583.333	0	0	0	0	0	2	4

Table 6: Amount of product, sent from each assembly to each customer in first period

Customer 4	Customer 3	Customer 2	Customer 1	Assembly
	1070.952		1360	1
1360	289.048	1440		2

Table 7: Amount of product, sent from each assembly to each customer in second period

Customer 4	Customer 3	Customer 2	Customer 1	Assembly
	1070.952		1360	1

1360	289.048	1440		2

Demand of customers, will be estimated completely:

Table 8: Cycle time for each assembly in each period

Second period	First period	Assembly
11.250	11.847	1
10.286	9.323	2

Table 9: Assigning task to a work station for assembly 1 in first period

Idle time	Cycle time	Tasks	Station
0.847	11.847	3,1,4	1
3.847	11.847	2,5	2
1.847	11.847	6,7,8	3

Table 10: Assigning task to a work station for assembly 1 in second period

Idle time	Cycle time	Tasks	Station
0.250	11.250	3,1,4	1
3.250	11.250	2,5	2
1.250	11.250	6,7,8	3

Table 11: Assigning task to a work station for assembly 2 in first period

Idle time	Cycle time	Task	Station
0.323	9.323	1,2,3	1
0.323	9.323	4,6	2
3.323	9.323	5	3
3.323	9.323	8	4

Table 12: Assigning task to a work station for assembly 2 in second period

Idle time	Cycle time	Task	Station
0.284	10.286	1,2,4	1
0.284	10.286	3,5	2
0.284	10.286	6,7,8	3

Table 13: Amount of production for each producer from each component in first period

Componen t7	Componen t6	Componen t5	Componen t4	Componen t3	Componen t2	Componen t1	Produc er
2510	2510	0	2120	4027.619	2989.048	2510	1
2750	166.667	2750	2750	2750	2750	2750	2
2380.952	2380.952	2380.952	2380.952	2380.952	2380.952	2380.952	3
3039.048	3039.048	2989.048	3039.048	1521.429	0	0	4

Table 14: Amount of production for each producer from each component in second period

Componen t7	Componen t6	Componen t5	Componen t4	Componen t3	Componen t2	Componen t1	Produce rs
0	0	2560	390	0	2560	0	1
0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	3
0	2583.333	0	0	0	0	0	4

Amount of production in first period is more than second, and that is because of the reason that keeping inventory cost, is less than production cost.

Table 15: Resources purchased by producers

Resource 2		Resource 1		
Second period	First period	Second period	First period	Period
16530	0	11020	0	Producer1
0	0	0	0	Producer2
0	0	0	0	Producer3
7750	0	5166.667	0	Producer4

According to the fact that at first for each producer, 50000 units from resources has been assigned, purchasing has done in second period. Also according to above calculation, the extra resources for each producer in all period (s_{mrp}), is equal to 0.

Conclusion:

The aim of this research was introducing an integrated model which considers "Assembly line balancing", "Production planning" and "Supply chain" coordinately. So producer's must specify their production plan and after that, they send their production to assemblies. The assemblies assemble the component to achieve the final product and they send the final products to

customers. Also assemblies must balance assembly line. Then we used Gams software to solve the model and implement that with a numerical example.

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