Integration of Reverse Supply Chain Network Optimization and Disassembly Line Balancing

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Outline

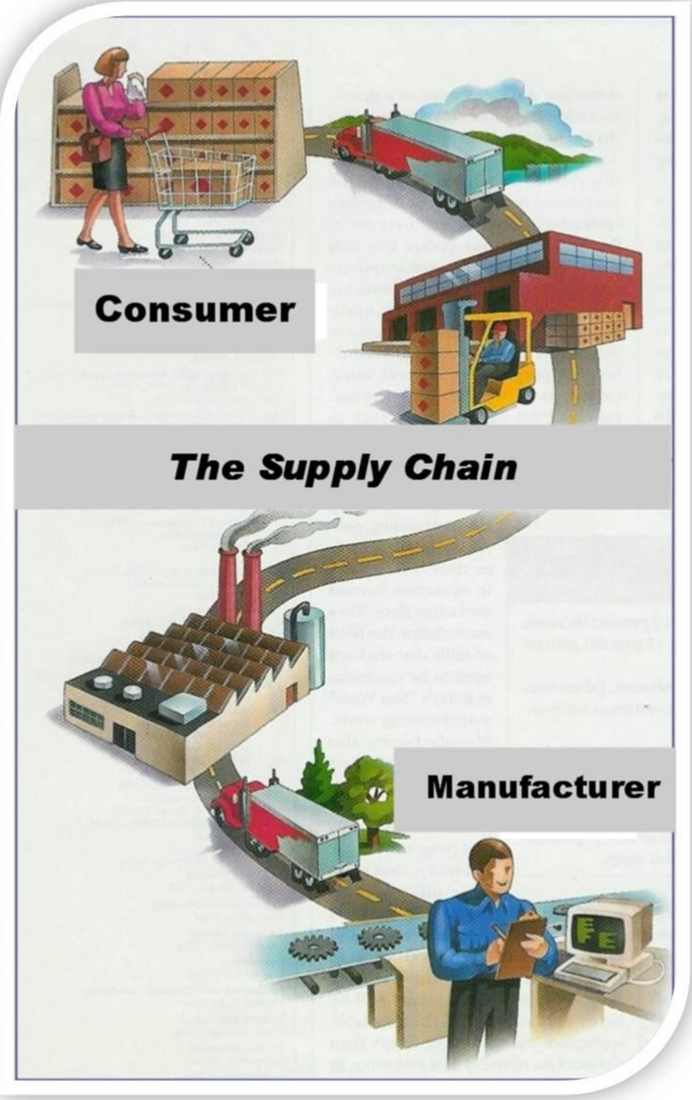
1. Introduction
2. Supply Chain Network Optimization
3. Reverse Supply Chains
4. Disassembly Line Balancing
5. Literature Survey
6. Developed Model: Integration of Two Problems
7. Results and Conclusion

Supply Chain

Supply Chain is a set of activities

* *purchasing,*
* *manufacturing,*
* *logistics,*
* *distribution,*
* *marketing*

that perform the function of delivering value to end customer



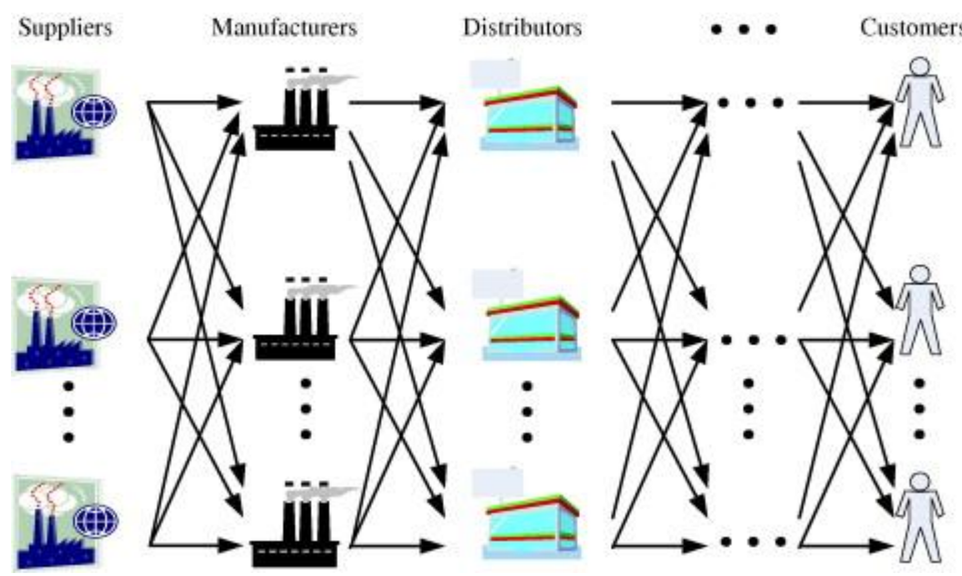
Today in Supply Chain

The supply chain with ***environmental impacts*** extends this definition by including:

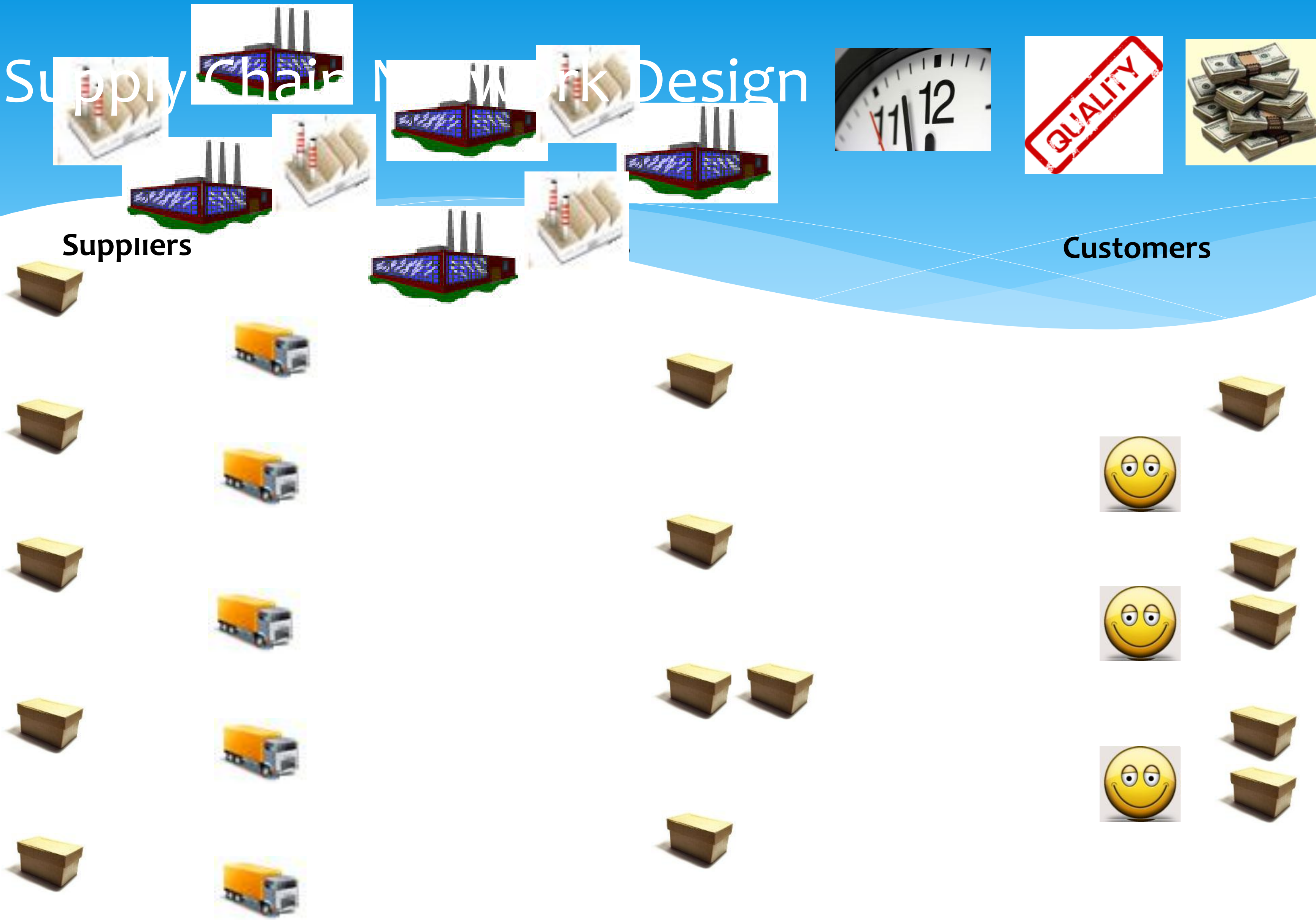
(i) ***Waste*** of all processes,
(ii) Using efficient ***energy*** resources,
(iii) Using ***capacities*** and ***resources efficiently***,
(iv) Considering legal ***environmental*** factors
(v) ***Recycling, reusing, refurbishing, disassembling***

Supply Chain Optimization

is ***determining*** positions and
count of actors,
amount of ***product flow*** between and
decreasing transportation costs are
handled as network design problem



Supply Chain Network Design



Current Situation

- While, ***2 kg*** of garbage per day in ***2010*** is producing by a human,
- By ***1990*** this figure is ***1 kg***
- Only ***3%*** of products consumed in the world are subjected to recycling

Recycling

* In **Germany**, according to the regulations which are forced in **1991**, companies have to recycle at least **60-70%** of product packages which are sold.

* **90%** of the cars damaged in road accidents in **Netherlands** have to be recovered.

* In USA, **20%** of glass, **30%** of papers and **61%** of cans are recycled per year.

* **"Dell to change"** program is implemented to gain profit through the used laptops by Dell.

Why ?

- Manufacturers ***recycling, remanufacturing*** and ***disassembling*** due to:

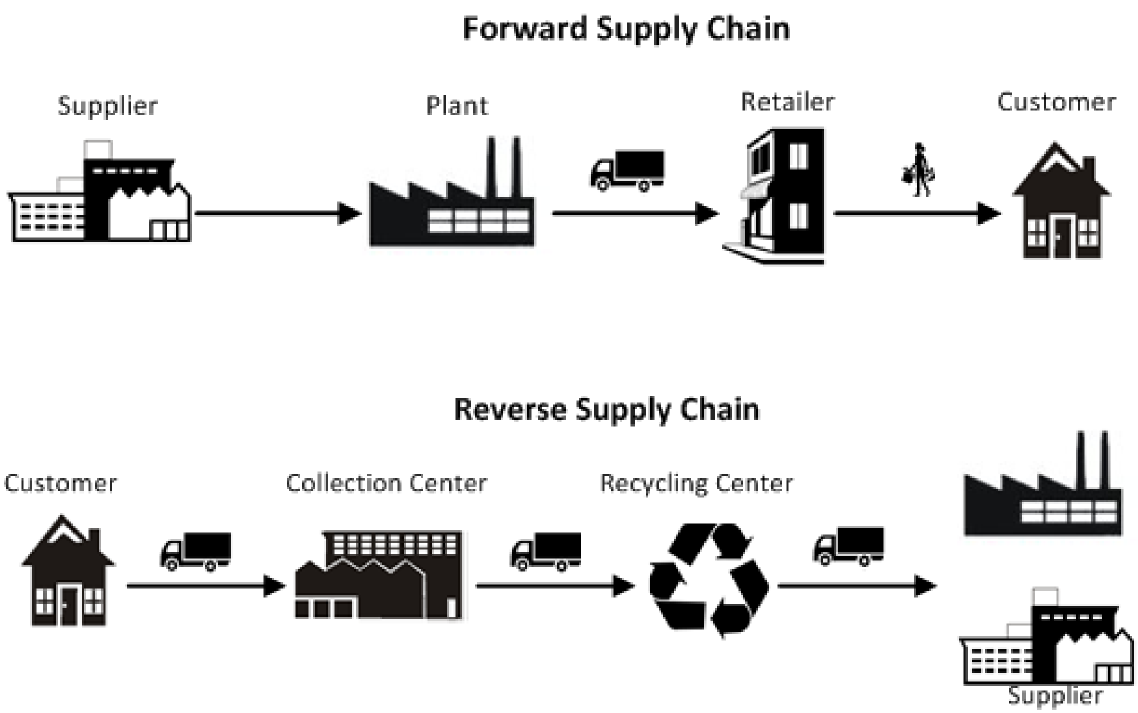
  - Implementation of extended manufacturer ***responsibility***
  - New more rigid ***environmental legislation***
  - Increased public ***awareness***
  - ***Economic attractiveness*** of reusing products and subassemblies or parts

Sentence of the Day

* ***"We cannot solve our problems with the same thinking we used when we created them"***

Albert Einstein

Reverse Supply Chain



While flow of material from source to end users in a supply chain is via the so-called ***forward chain***;

Recent interest in supply chains lies in the recovery of products, which is typically achieved through processes such as repair, remanufacturing, disassembling and recycling, are collectively termed ***reverse chain*** activities

Differences
Between Forward and Reverse Logistics

Forward supply chain	Reverse supply chain
Easier to forecast	Harder to forecast
Profit benefit oriented	Environmentally benign product benefit oriented
Distribution to multiple locations from a single source	Distribution to a single location from multiple sources
Stable product quality	Unstable product quality
Stable product packaging	Unstable product packaging
Stable product structure	Unstable product structure
Route of distribution is known/determined	Route of distribution is unknown/undetermined
Known main characteristics	Unknown main characteristics
More or less stable pricing	Pricing is effected by various factors/less stable
Speed is important	Speed is not a factor
Easily visualized cost factors	Hard to determine the costs
Stable inventory management	Unstable inventory management
Manageable product life cycle	More complicated product life cycle
Well known marketing techniques	Marketing techniques involve more complicated factors
Clearly observed processes	Less visible process

Reverse Supply Chain Activities

Recycling

Reusing

Disassembling

Refurbishing

Disposal

Motivation behind the talk!

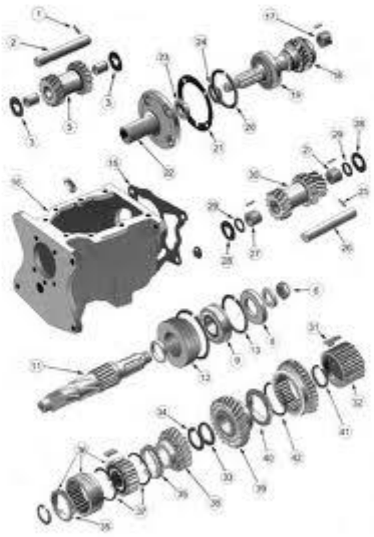
Disassembly process of reverse supply chain is the main ***problem*** while optimizing the reverse supply chain

Disassembly line balancing

Disassembly and Disassembly Line Balancing

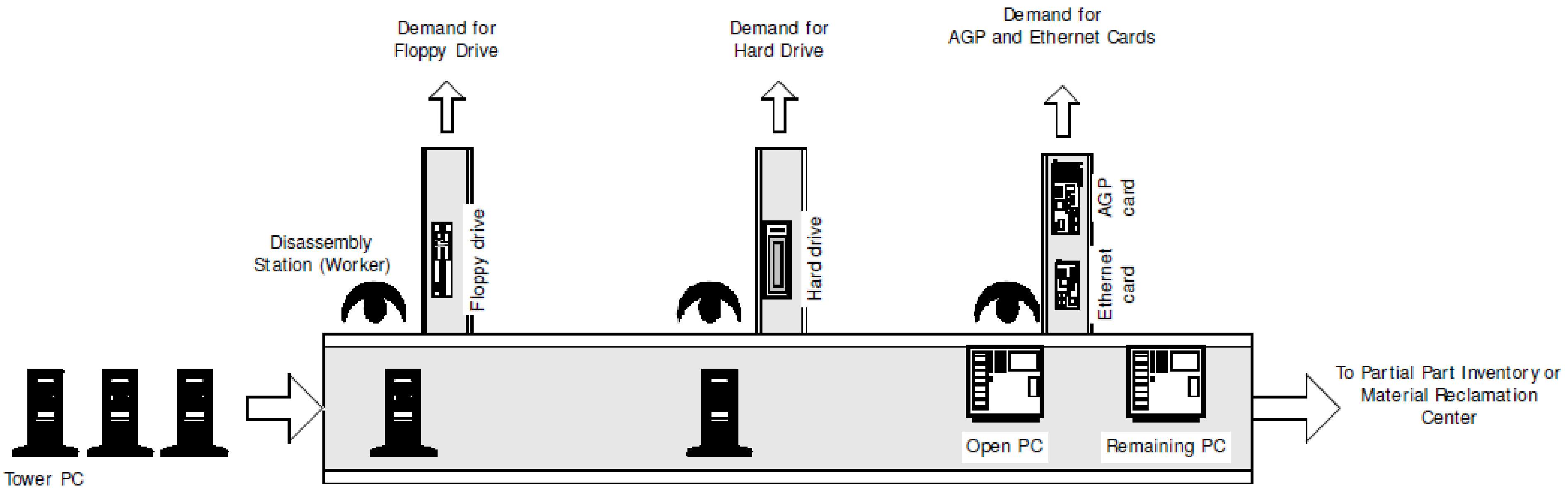
- According to extensive research by Güngör and Gupta (1999a) and Ilgın and Gupta (2010), the ***first crucial step*** of RSC and product recovery processes is ***disassembly***.

- ***Disassembly*** is defined as a systematic method for ***separating*** a ***product*** into its ***constituent parts***, ***subassemblies*** or ***other groupings***.

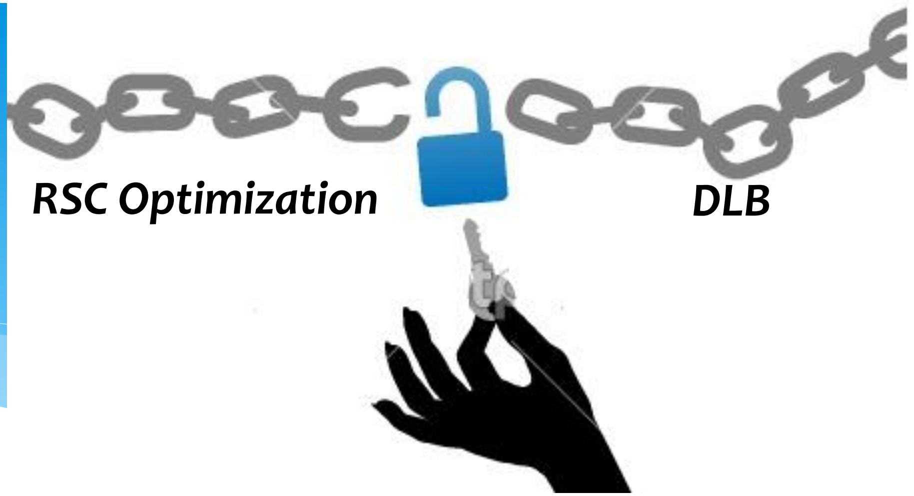


Disassembly Line Balancing

* The basic DLB problem can be stated as the assignment of ***disassembly tasks*** to an ordered ***sequence*** of ***stations*** such that all the ***disassembly precedence*** relations are ***satisfied*** to optimize some performance measures as ***stations***, ***cycle*** time, ***profit*** and etc.



Goal of the Study



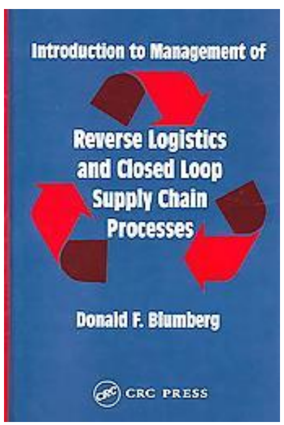
* ***Disassembly line*** and ***reverse distribution*** processes have to be able to work ***simultaneously***.

* Visibility of the whole ***disassembling*** and ***distribution process*** that will lead to more ***accuracy***, ***reliability*** and ***controllability*** should be provided by this integration.

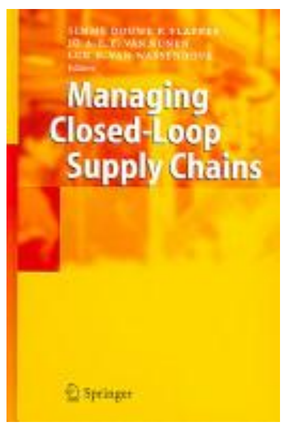
* While enterprises try to ***minimize*** their own ***transportation costs*** through the RSC network to achieve ***recycling*** and ***recovery*** of used products; on the other hand, they struggle to optimize the operations of ***disassembly lines***.

Literature of RSC Optimization

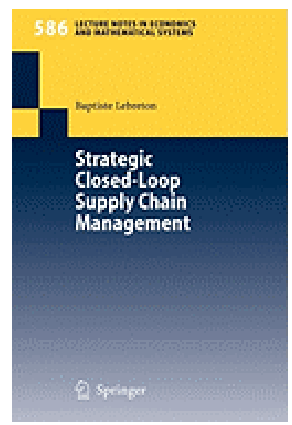
- Literatür surveys
  - Fleischmann ve ark. (1997)
  - Sasikumar and Kannan (2008a; 2008b; 2009)
  - Akçalı ve ark. (2009)
- Books



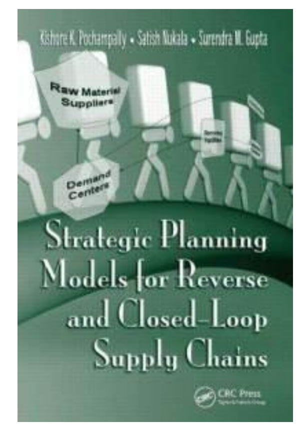
Blumberg (2005)



Flapper ve ark. (2005)



Lebreton (2007)



Pochampally ve ark. (2009)

Literature Matrix of RSC Network Design

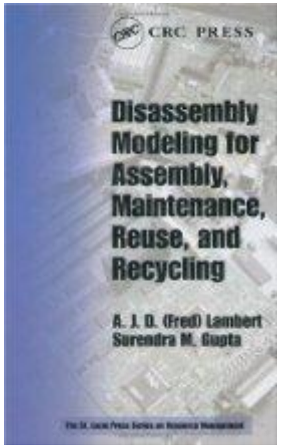
Model Properties	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]
Network Structure																	
Closed-Loop	■	■					■		■	■	■	■	■		■	■	■
Reverse			■	■	■	■		■						■			
Objective Function																	
Minimizing	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■
Maximizing							■										
Multi Objective				■		■					■			■			■
Facility Location																	
Fixed Location			■							■						■	■
Discrete Location	■	■		■	■	■	■	■	■		■	■	■	■	■		
Product Type																	
One Product	■	■		■			■		■			■		■	■		■
Multi Product			■		■	■		■		■	■		■			■	
Period Type																	
Static	■	■	■	■	■	■	■	■			■	■		■	■	■	■
Dynamic									■	■			■				
Components																	
None	■	■		■	■	■	■		■		■	■		■	■	■	
Available			■					■		■			■				■
Solution Approach																	
Linear Programming																■	■
Mixed Integer Programming	■	■	■	■	■	■	■				■			■	■		
Nonlinear Programming																	
Stochastic Programming																	
Fuzzy Programming									■								
Goal Programming																	
Heuristics								■		■		■	■				
Simulation																	
Parameters and Variables																	
Transporation Costs	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Environmental Costs																	■
Inventory Costs	■	■		■		■				■	■			■		■	
Remanufacturing Costs	■	■	■	■	■	■		■	■	■	■		■	■	■	■	■
Delivery Time									■								
Profit							■										

Authors

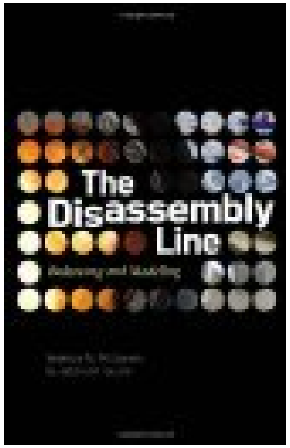
[1] Jayaraman ve ark. (1999)
[2] Fleishmann ve ark. (2001)
[3] Krikke ve ark. (2003)
[4] Beamon ve Fernandes (2004)
[5] Salema ve ark. (2007)
[6] Demirel ve Gökçen (2008)
[7] Yang ve ark. (2009)
[8] Lee ve ark. (2009)
[9] Pishvaee ve Torabi (2010)
[10] Kannan ve ark. (2010)
[11] Easwaran ve Üster (2010)
[12] Wang ve Hsu (2010)
[13] Kumar ve ark. (2010)
[14] Khajavi ve ark. (2011)
[15] Pishvaee ve ark. (2011)
[16] Shi ve ark. (2011)
[17] Paksoy ve ark. (2011)

Literature of DLB

- Books



Lambert ve Gupta (2005)



McGovern ve Gupta (2010)

Studies on DLB

Year	Authors	Goal	Aprroach
2001	Güngör and Gupta	Cost minimization	Heuristic
2003	McGovern and Gupta	Station number and idle time minimization	2-Opt algorithm
2007a	McGovern and Gupta	Station number and idle time minimization	Genetic algorithm Ant colony optimization Greedy algorithm Greedy/Hill climbing algorithm Greedy/2-Opt algorithm
2007b	McGovern and Gupta	Station number and idle time minimization Hazardous parts priority to be disassembled	Genetic algorithm
2008	Agrawal and Tiwari	Station number minimization	Ant colony optimization Stochastic programming
2008	Altekin et al.	Profit maximization	Mixed integer programming
2009	Koç et al.	Station number minimization	Mixed integer programming
2010	Ding et al.	Station number and idle time minimization	Ant colony optimization

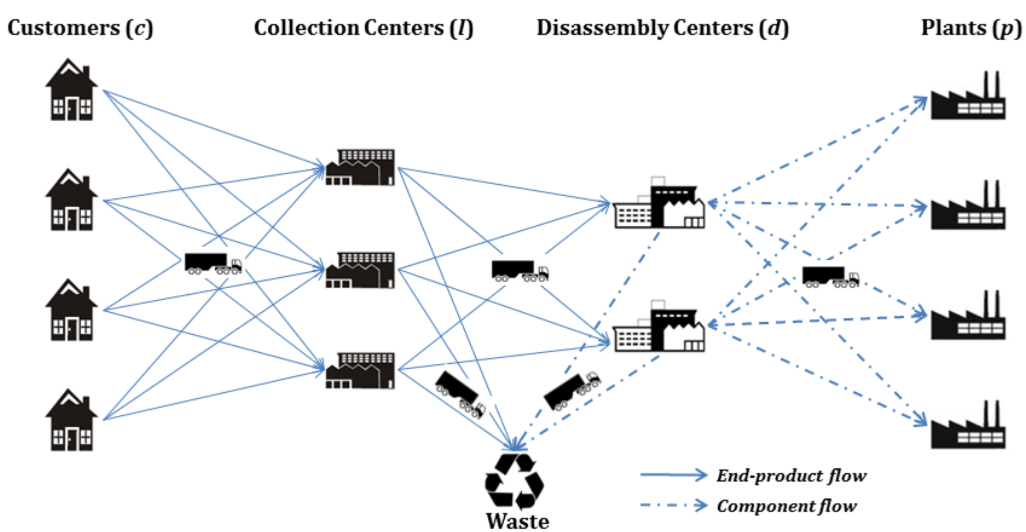
Contribution and aim of study

- Most studies fail to properly integrate ***production***, ***assembling***, ***disassembling*** activities and the more traditional operational and economic objectives in ***reverse chain network problems.***
- First study which integrates ***RSC optimization*** and ***DLB***
- First study which considers ***cycle time*** as a ***variable*** in DLB
- First study which uses ***nonlinear programming***

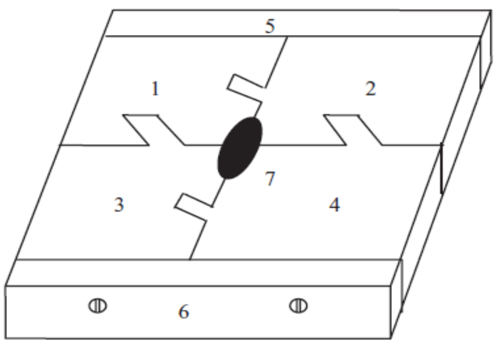
Problem Definition and Modeling

Indices

c	index of customers *c=1, 2, ….C;*	*k*	index of components *k=1, 2,… K;*
l	index of collection centers *l=1, 2,… L;*	*j*	index of stations *j=1, 2,… J;*
d	index of disassembly centers *d=1, 2,… D;*	*a*	index of artificial nodes *a=1, 2,… A;*
p	index of plants *p=1, 2,… P;*	*i*	index of tasks *i=1, 2,… .I.*

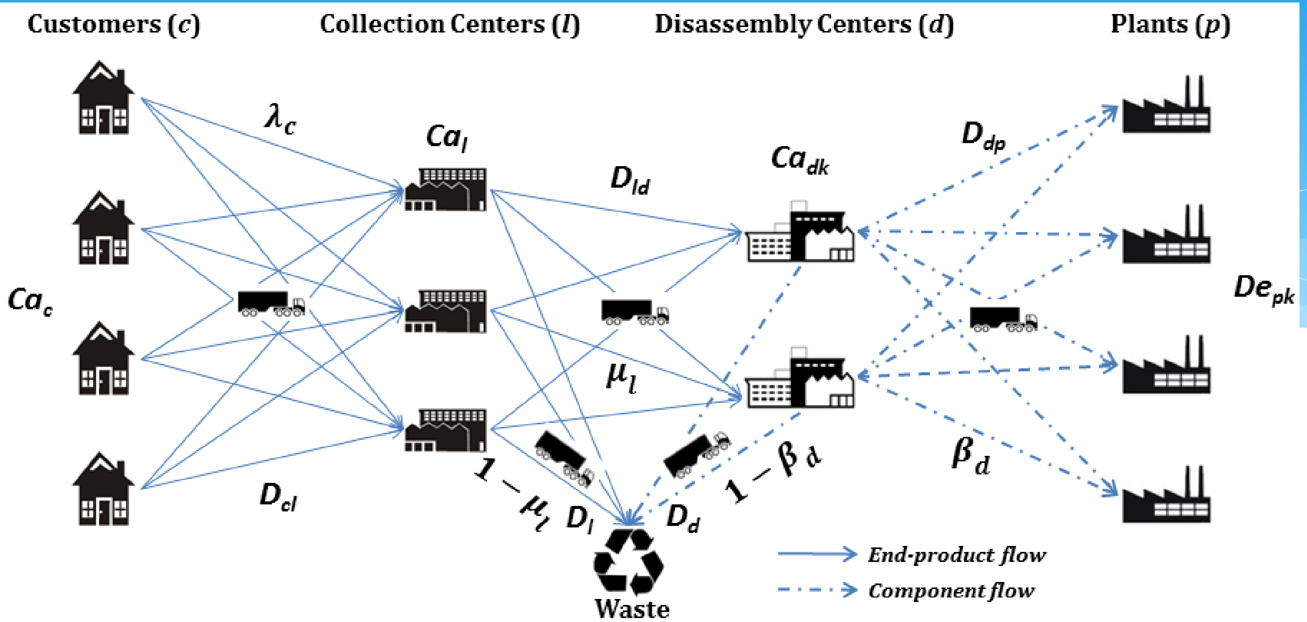


Network structure



End-Product with its 7 components

Sets and Parameters



A_a	artificial nodes
B_i	normal nodes
d_{Bi}	task time (normal node) of B_i (time units)
$P(A_a)$, $P(B_i)$	immediate predecessor set of A_a, B_i, respectively
$S(A_a)$, $S(B_i)$	immediate successor set of artificial node A_a, B_i, respectively
J	number of stations (upper bound) estimated from a heuristic procedure
W_{time}	working time (time units)
C_t	cost of shipping ($/ton*km)
O	fixed cost to open a station in the disassembly line ($)
r_k	number of component *k* in disassembling one unit of product

Variables

Q_{cl}	amount shipped from customer *c* to collection center *d* (units)
Y_{ld}	amount shipped from collection center *l* to disassembly center *d* (units)
N_l	amount shipped from collection center *l* to waste (units)
W_{dpk}	amount shipped from disassembly center *d* to plant *p* for component *k* (units)
V_{dk}	amount shipped from disassembly center *d* to waste for component *k* (units)
CT_d	cycle time for disassembly center *d* (time units)
X_{ijd}	1, if task B_i is assigned to station *j* in disassembly center *d*; 0 otherwise
F_{jd}	1, if station *j* is opened in disassembly center *d*; 0 otherwise
Z_{id}	1, if task B_i is performed in disassembly center *d*; 0 otherwise

Objective Function and Constraints

minimizes the total shipping costs of all echelons

$$Obj1 = C_t . (\sum_c^C \sum_l^L Q_{cl} . D_{cl} + \sum_l^L \sum_d^D Y_{ld} . D_{ld} + \sum_l^L N_l . D_l + \sum_d^D \sum_p^P \sum_k^K W_{dpk} . D_{dk} + \sum_d^D \sum_k^K V_{dk} . D_d) + \qquad (1)$$

minimizes the total fixed costs for operating the disassembly stations in the disassembly centers

$$Obj2 = O . \sum_j^J \sum_d^D F_{jd} . j \qquad (2)$$

Constraints (3) and (4) guarantee that exactly one of the OR-successors is selected in all disassembly centers. Thus, given two constraints provide a solution to be a set of tasks that includes a DT.

$$\sum_{i:B_i \in S(A_a)}^I Z_{id} = 1 \qquad \forall_{a=0,d} \qquad (3)$$

$$\sum_{i:B_i \in S(A_a)}^I Z_{id} = \sum_{i:B_i \in P(A_a)}^I Z_{id} \qquad \forall_{a \neq 0,d} \qquad (4)$$

Constraint (5) is the assignment constraint and ensures that each disassembly task is assigned to exactly one station in all disassembly centers.

$$\sum_j^J X_{ijd} = Z_{id} \qquad \forall_{i,d} \qquad (5)$$

Constraints

Constraint (6) is known as the precedence constraint and provides that the selected successor is not assigned to a lower indexed station than the one to which the selected predecessor is assigned in all disassembly centers

$$\sum_{i:B_i \in P(A_a)}^{I} \sum_{j}^{h} X_{ijd} \geq \sum_{i:B_i \in S(A_a)}^{I} X_{ihd} \qquad \forall_{a \neq 0, h \in J, d} \qquad (6)$$

Constraint (7) is the cycle time constraint and prevents the cycle time being exceeded for a disassembly station in all disassembly centers.

$$\sum_{i}^{I} X_{ijd} . d_{B_i} \leq CT_d . F_{jd} \qquad \forall_{j,d} \qquad (7)$$

Constraint (8) shows that the cycle time in all disassembly centers is equal to the total working time divided by the total component quantity that is disassembled for all disassembly centers.

$$CT_d = (W_{time} / (\sum_{p}^{P} \sum_{k}^{K} W_{dpk} + \sum_{k}^{K} V_{dk})) . F_{jd} \qquad \forall_{j,d} \qquad (8)$$

Constraints

Constraint (9) ensures that a percentage of total used products at each customer are collected.

$\sum_l^L Q_{cl} \leq \lambda_c . Ca_c \qquad \forall_c \qquad (9)$

Constraints (10) and (11) ensures the capacities of collection centers and disassembly centers.

$\sum_d^D Y_{ld} + N_l \leq Ca_l \qquad \forall_l \qquad (10)$

$\sum_p^P W_{dpk} + V_{dk} \leq Ca_{dk} \qquad \forall_{d,k} \qquad (11)$

Constraint (12) gives the satisfaction of plant demand for all components.

$\sum_d^D W_{dpk} \geq De_{pk} \qquad \forall_{p,k} \qquad (12)$

Constraints (13-16) guarentee the reverse flows.

$\mu_l . \sum_c^C Q_{cl} = \sum_d^D Y_{ld} \qquad \forall_l \qquad (13)$

$(1-\mu_l) . \sum_c^C Q_{cl} = N_l \qquad \forall_l \qquad (14)$

$r_k . \beta_d . \sum_l^L Y_{ld} = \sum_p^P W_{dpk} \qquad \forall_{d,k} \qquad (15)$

$r_k . (1-\beta_d) . \sum_l^L Y_{ld} = V_{dk} \qquad \forall_{d,k} \qquad (16)$

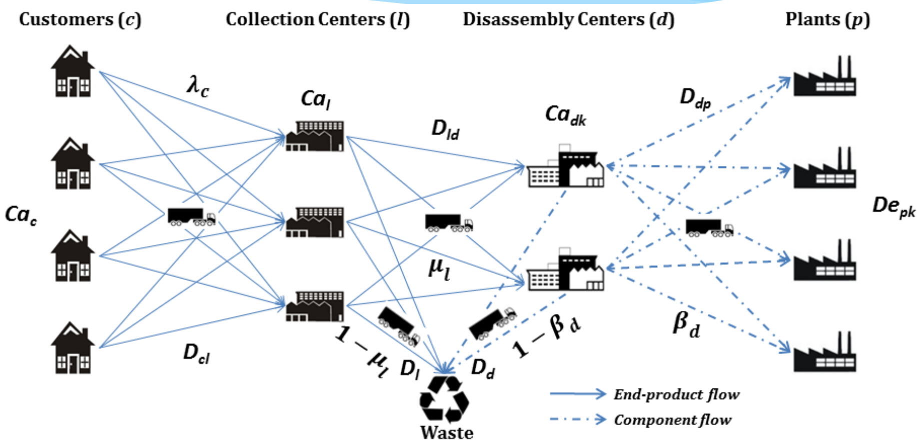
Constraints (17-18) enforces the non-negativity restriction and binary variables.

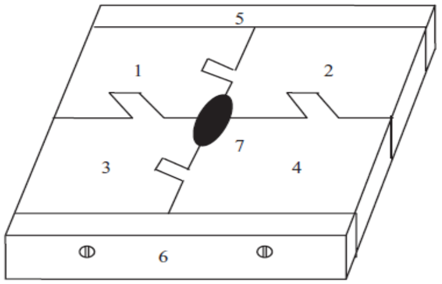
$Q_{cl}, Y_{ld}, N_l, W_{dpk}, V_{dk}, CT_d \geq 0 \qquad \forall_{c,l,d,k} \qquad (17)$

$X_{ijd}, F_{jd}, Z_{id} \in \{0,1\} \qquad \forall_{i,j,d} \qquad (18)$

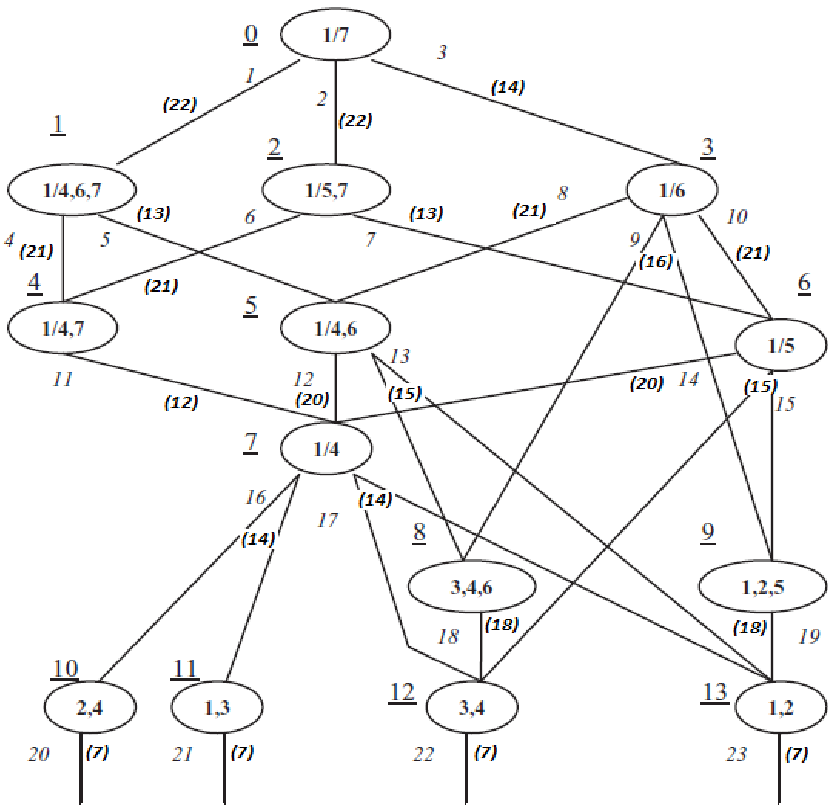
Computational Experiments

- Instances, except DLB problem (Koç et al. 2009), are produced, based on randomly generated parameters.
- The considered RSC includes ***four*** customers, ***three*** collection centers, ***two*** disassembly centers, ***four*** plants and waste.
- In the proposed RSC network, the reverse flow is for either (i) ***collection***, (ii) ***disassembling*** or (iii) ***disposal*** of a used product that consists of ***seven*** different components.





Computational Experiments



- End product is disassembled into ***seven*** different ***components*** in the disassemblers according to the precedence graph.
- The figure also shows the precedence graph with ***23 tasks*** (with italic) and ***13 artificial nodes*** (with bottom line) with ***task times between 7 and 22*** (in parentheses).
- The numbers within the nodes represent the related subassembly.
- For example, in node **2 (2)** the ***component 6*** is taken away from the product and the resulting subassembly consists of ***components 1*** through ***5 (i.e., 1/5)*** and ***component 7.***

Other Relevant Data

Table 1. Components capacities of disassembly centers and plants

	Components						
	1	2	3	4	5	6	7
Disassembly center 1	1700	2100	1800	2300	1900	2300	2200
Disassembly center 2	1700	1800	1900	1600	1700	1800	1900
Plant 1	360	400	300	340	300	370	400
Plant 2	300	150	400	360	300	380	300
Plant 3	200	400	340	300	300	270	360
Plant 4	400	300	200	480	300	250	350

Table 2. Distances between each facility

	Collection centers			Plants				Waste
	1	2	3	1	2	3	4	
Customer 1	280	350	300	-	-	-	-	-
Customer 2	250	200	260	-	-	-	-	-
Customer 3	310	330	290	-	-	-	-	-
Customer 4	270	205	320	-	-	-	-	-
Disassembly center 1	140	110	230	420	350	370	310	100
Disassembly center 2	180	170	150	290	345	190	230	130
Waste	50	80	75	-	-	-	-	-

Table 3. Products at customers and capacities of collection centers

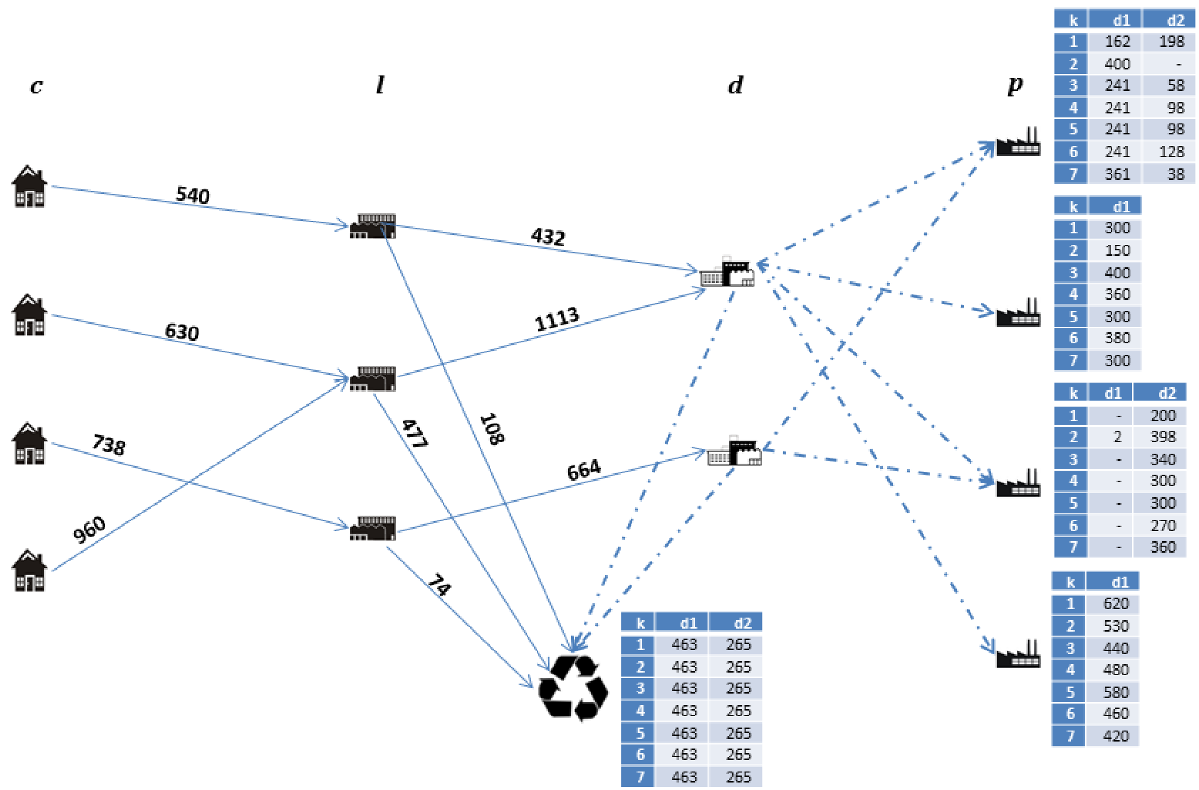
Customers				Collection centers		
1	2	3	4	1	2	3
2300	2100	2200	2400	2200	2500	2100

* (C_t) is given as 5.23 cents per ton-km Forkenbrock (2001)
* Fixed cost (O) to open a station is set to 100$/station
* W_{time} is set to 200000 time units
* Maximum available station number (J) is set to 6
* $\lambda_{1,2,3,4}$= 60%, 30%, 50%, and 40%
* $\mu_{1,2,3}$= 80%, 70%, and 90%
* $\beta_{1,2}$= 70% and 60%.

Results

* The proposed model is solved via GAMS/BARON solver on a Pentium IV PC, running at 1.33 GHz (4GB RAM) and takes 27 minutes 17 seconds.

* The total transportation cost is 9269.04$.
* In total, 7 stations are opened with 700$.
* 2868 units of used products are collected from customers.
* After the inspection in collection centers, 659 units of them are disposed and rest of them are sent to disassembly centers.
* While 5096 units of disassembled components are disposed, rest of disassembled components is transported to plants.



k	d1	d2
1	162	198
2	400	-
3	241	58
4	241	98
5	241	98
6	241	128
7	361	38

k	d1
1	300
2	150
3	400
4	360
5	300
6	380
7	300

k	d1	d2
1	-	200
2	2	398
3	-	340
4	-	300
5	-	300
6	-	270
7	-	360

k	d1
1	620
2	530
3	440
4	480
5	580
6	460
7	420

k	d1	d2
1	463	265
2	463	265
3	463	265
4	463	265
5	463	265
6	463	265
7	463	265

Results

* According to the optimal results, the cycle times per disassembler are determined as:

$$CT_1 = \frac{W_{time}}{\sum_p^P \sum_k^K W_{1pk} + \sum_k^K V_{1k}} = \frac{200000}{10850} = 18.43 \; time \; units$$

$$CT_2 = \frac{W_{time}}{\sum_p^P \sum_k^K W_{2pk} + \sum_k^K V_{2k}} = \frac{200000}{4641} = 43.09 \; time \; units$$

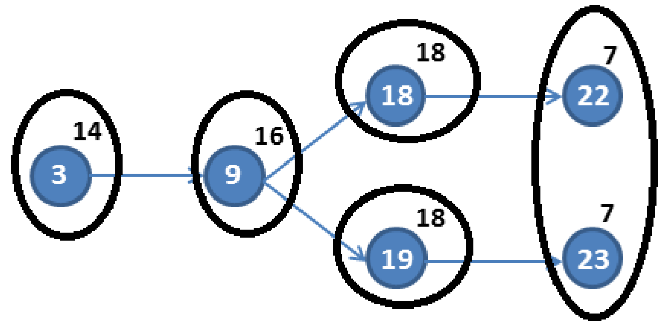
Table 4. Optimal line balancing for the first disassembler

Workstation	Tasks assigned	Workstation time	Idle time
1	3	14	4.43
2	9	16	2.43
3	18	18	0.43
4	19	18	0.43
5	22-23	14	4.43
Total		80	12.15

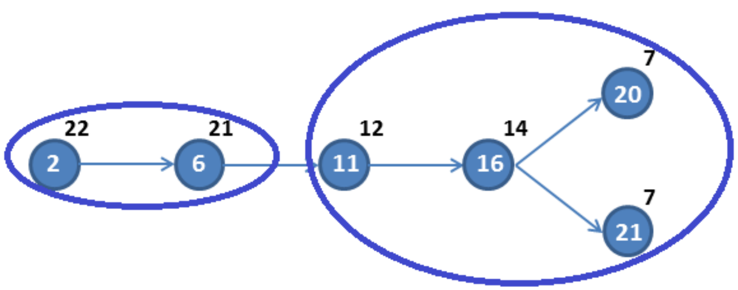
Table 5. Optimal line balancing for the first disassembler

Workstation	Tasks assigned	Workstation time	Idle time
1	2-6	43	0.09
2	11-16-20-21	40	3.09
Total		83	3.18

Balanced disassembly diagram of disassembler 1

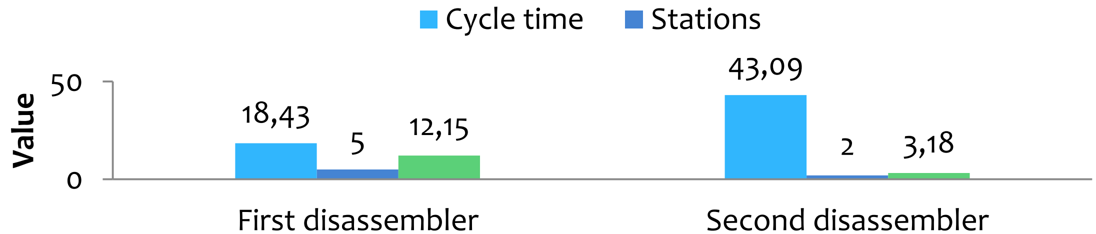


Balanced disassembly diagram of disassembler 2



Results

- The maximum cycle time (43.09) and as expected minimum stations (2) are obtained in disassembler 2.
- DLB in disassembler 2 is more balanced than in disassembler 1 with 3.18 TU idle times.
- The minimum cycle time (18.43) and maximum stations (5) are in disassembler 1.
- In fact, there are 17 unique ways, which have different disassembling time, of completely disassembling the product .
- For this illustrative example, two of them are obtained.
- The solution to the test problem shows that the proposed model is valid and useful for optimizing RSC design and disassembly lines simultaneously.



Conclusion & Suggestions

- The main objective of this paper is to introduce the problem of integrating ***RSC network design*** and ***DLB*** problems.
- To achieve this goal, a ***novel nonlinear mixed-integer programming*** formulation is developed.
- The proposed mathematical model seeks the ***optimal distribution network,*** which involves ***collection***, ***disposal*** and ***disassembling processes***, while ***balancing*** the ***disassembly lines*** in each disassembler ***simultaneously***.
- To the best knowledge of authors, proposed study is the first study of the simultaneous ***optimization*** of the ***RSC network*** and ***disassembly lines***.
- For future researches, ***efficient heuristic*** and ***meta-heuristic approaches*** should be developed to solve proposed problem in a ***reasonable time***.
- In addition, different types of disassembly lines such as ***parallel*** or ***mixed*** and different types of networks such as ***closed-loop*** or ***open-loop*** supply chains should be integrated.
- Finally, the ***uncertainty*** in ***demand***, ***recovery rates*** and especially ***DLB*** process should be examined in a ***fuzzy approach*** to facilitate real applications.

Thank You

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