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An Experimental Research on Closed Loop Supply Chain Management with Internet of Things

By Turan PAKSOY [†],
İsmail KARAOĞLAN, Hadi GÖKÇEN,
Panos M. PARDALOS & Belkıs TORĞUL

Abstract. Closed loop supply chain (CLSC) optimization is integration of forward and reverse logistics activities. The importance of CLSC management is increasing by legal regulations, limited energy resources and environmental- financial problems that growing in recent years. However, reverse logistics part of the CLSC is a flow type which is more difficult to made predictions, planning and controls by reason contained uncertainties. This stage, Internet of Things system reduces related uncertainties by providing all the life information of the returned product and substantially attenuates planning of reverse flow activities. In this study, a CLSC is considered that meets demands of the sales&collection center both new and remanufactured product. Manufacturer has three options (refurbishing, disassembly and disposal) to assessing returned products. A mixed integer linear programming model is proposed for a single type of product is completely modular (automobile, computer, telephone, etc.). The model meets customer's products and components demands based period, maximizes profit consist of different sales revenues and total cost (total production, purchase, transportation and disposal costs) and determines how to evaluate all returned products. The proposed model has been verified with the aid of a numerical example by solving in GAMS software and its performance reviewed with experimental studies.
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1. Introduction

Supply chain is a system covering the product life cycle processes of product or service and comprising the entire of passed operations until it reaches to hand of end-customer from raw material, information flow, physical distribution and shopping. Long years, the structures that supply chain management interested and whose flow direction is from raw materials to final users is called forward supply chain (FSC) (Salema et al., 2009). However, increasing the flow of returned products to manufacturer made an effective product recovery network design necessary due to government regulations and customers' environmental awareness. This product recovery network must be provided with an integration of forward and reverse flow network known as closed-loop supply chain (CSLC) (Özceylan & Paksoy, 2013b).

† SelcukUniversity, Faculty of Engineering, Industrial Engineering Department, Konya, Turkey.
☎. +90 332 223 2040
✉. tpaksoy@yahoo.com

In CLSC network, is not only tracking a linear way leading to consumer from producer (assembly process) but also it is subject to completion of the cycle covering a way that is towards to producer from consumer(disassembly process). Therefore, a source of raw materials of reverse supply chain (RSC) and CLSC is not suppliers as it is in FSC, in contrast it is end-users or customers (Ozceylan, 2013). Remanufacturing of used products and bringing them back to the market provides not only the environmental and customer benefits to original equipment manufacturers but it also reduces their production cost. Compared with normal production, manufacturers can save about 40–60% of the cost while paying for only 20% of the manufacturing effort. Kim, Raichur, and Skerlos (2008) demonstrated that a remanufactured product uses less than 20% of the materials, 16% of the energy and releases only 35% of the greenhouse gas emissions of those released in the process of producing a new product (Jindal & Sangwan, 2014).

Manufacturer in CLSC performs both manufacturing and remanufacturing activities using new parts purchased from external suppliers and parts recovered from returned products. But application rates of different product recovery options such as reuse, refurbishing, remanufacturing, recycling and disposal change constantly due to the amount, quality and time of the returned product is quite uncertain. The uncertainties in the reverse flow make planning of entire chain difficult affecting the forward flow. Since the life cycle information of a product is unknown, inspection and testing become necessary to determine the conditions of returned products and their components. When a component turns out to be nonfunctional after testing, the time and effort made in disassembling and testing that component are wasted (Ondemir & Gupta, 2014a). It can also be quite expensive to test all returned products and their components. Internet of Things (IoT) makes returned product management easier reducing or almost eliminating uncertainty in reverse flow.

IoT is a common worldwide network which in a unique way addressable things / objects created by them selves and the objects in the network are in contact each other with a specific protocol (Kutup, 2011). Use of the IoT has been proposed for various segments of supply chains including reverse logistic. By means of this network, all objects can be monitored and tracked. Radio-frequency identification (RFID) is considered to be the core component and the enabler of such a structure. Although passive RFID tags are sufficient for tracking purposes, active RFID tags with embedded sensors can provide a lot more information about the usage/condition of every single object (Ondemir & Gupta, 2014b). Sensor detects the changes in the value of various measures such as temperature, pressure, vibration and humidity and converts the signal to be recorded. RFID tag containing static information such as serial number, model, bill of materials, production date, delivery date of the product is connected to the product and can be updated after the operations such as each maintenance, improvement. Dynamic information such as environmental conditions occurring during use of the product, working time and frequency of the product is recorded with the help of sensors.

The purpose of the study, apply IoT system to deal with uncertainty in CLSC and thanks to the information provided by this system both eliminate costly preliminary inspection and disassembly operations and evaluate and use effectively all returned products.

Following the introduction, a literature survey on the issue is included in second section. The considered problem is defined and developed model is explained in third section. Then related model is tested with a numerical example in GAMS package program and obtained results are interpreted. The performance of proposed model is tested with experimental studies in fourth section. And study is terminated with last section namely conclusion.

2. Literature Review

The popularization of recycling showed a significant increase in academic studies related to both RSC and CLSC network design and cost minimization approach of manufacturers has been replaced to revenue opportunity approach.

Some of the first comprehensive studies in reverse and CLSC networks were presented by Fleischmann et al. (1997, 2000), who view reverse and CLSC network planning in three main areas, namely, distribution planning, inventory control, and production planning. In a later study, Fleischmann et al. (2001) considered the integration of forward and reverse chains using case studies on photocopier remanufacturing and paper recycling. Their results showed that there is a potential for cost savings if one takes an integrated view rather than a sequential design of forward and reverse distribution networks.

Krikke et al. (2001) provided an integrated approach using a MILP model for draw attention to a variety of product designs and CLSC. Guide et al. (2003) emphasized CLSC for product recovery. Beamon and Fernandes (2004) evaluated the decision to open the storage and collection centers by developing a multi-term closed-loop supply chain produced both zero and remanufactured products. Sheu et al. (2005), presented a multi-purpose optimization model to maximize the net profit based on both forward and reverse supply chain and showed that the model provides 21% increase net profit of network with numerical examples. Min et al. (2006) proposed a mixed-integer, non-linear programming model and genetic algorithm for its solution containing both spatial and temporal consolidation retured products. Jayaraman (2006), presented an analytical approach towards to production planning and control for CLSCs with product recovery and reuse. Kumar and Craig (2007) studied on Dell's closed-loop supply chain. Pagell et al. (2007) examined four general recycling options and their effects. Jun et al. (2007) examined the product life-cycle management through three main stages. Which are Beginning of life, including design and production; Middle of life, including distribution, use, service and maintenance; End of life, including collecting, remanufacturing, reuse, recycling and disposal. Salema et al. (2007) proposed a mixed integer linear programming model for a reverse logistics network design with multi-product, single-period and capacity limit to deal with uncertainty in product demand and return. Guide and Van Wassenhove (2009), observed complexity of closed-loop supply chain and introduced it with a strong business perspective to reader. They examined this evolutionary process of CLSC network in five stages. Yang et al. (2009), developed ageneral CLSC network model including raw material suppliers, manufacturers, retailers, customers and recovery centers. Their studies aim to optimize the balance condition of the network using the theory of variational inequalities. Gupta and Evans (2009) proposed a non-preemptive goal programming approach to model a closed-loop supply chain network. Pishvaee and Torabi (2010) proposed a bi-objective possibilistic mixed integer programming model to deal with uncertain and imprecise parameters in CLSC network design problems. Kannan et al. (2010) developed a multi-echelon, multi-period, multi-product CLSC network model for product returns, in which decisions are made regarding material procurement, production, distribution, recycling, and disposal. They proposed heuristics based genetic algorithm and applied it as a solution methodology to solve mixed integer linear programming model. Paksoy et al. (2011) presented a integer linear programming model to trade off between cost of CO_2 emissions released in transport activities and transport costs in a CLSC network. Akçalı and Cetinkaya (2011), evaluated several articles on inventory and production planning for CLSC categorizing existing work in deterministic and stochastic problems. Zeballos et al. (2012) introduced a scenariobased modeling approach with two-stage, to deal with the design and planning decisions in multi-period, multi-product CLSC under uncertainty.

More recently, Özceylan and Paksoy (2013) proposed a mixed integer mathematical model for multi-period and multi-part CLSC network. The proposed model gives optimal values of produced and disassembled products in CLSCs determining the location of factories and retailers. Amin and Zhang (2013) proposed a stochastic mixed integer linear programming model for a single-period, multi-period CLSC including multiple plants, collection center and demand market problem. The model taking into account environmental factors and uncertainty of demand and returned product aims to minimize total cost. Pazhani et al. (2013) addressed a bi-objective network design problem for multi-period, multi-product CLSC to minimize the total supply chain costs and to maximize the service efficiency of the warehouses and hybrid facilities. They developed a bi-objective mixed integer linear programming model to assist location, operating, production and distribution decisions. Zeballoset al. (2014) addressed general multi-period, multi-product closed-loop supply chain which is structured as a 10-layer network (5 forward plus 5 reverse flows) with uncertain levels in the amount of raw material supplies and customer demands. MILP model proposed to design and planning of the network minimizes the total cost including facilities, purchasing, storage, transport and emissions costs minus the total revenue obtaining from returns. Jindal and Sangwan (2014) proposed a multi-product, multi- facility CLSC network in an uncertain enviroment, which includes reuse, refurbish, recycle and disposal of parts. It was proposed a fuzzy mixed integer linear programming model to optimize the location and allocation of parts at each facility and number of parts to be purchased from external suppliers in order to maximise the profit of organisation. Ramezani et al. (2014) designed a CLSC including strategic and tactical decisions in fuzzy environment. The model consists of three objective functions including profit maximization, time minimization and minimization of defective parts obtained from suppliers.

Özceylan et al. (2014) described an integrated model that jointly optimizes the strategic and tactical decisions of a CLSC. Proposed nonlinear mixed integer programming model aims to minimize costs of transportation, purchasing, refurbishing, and operating the disassembly workstations. Govindan et al. (2015) reviewed recently published papers in reverse logistic and closed-loop supply chain in scientific journals. They selected and reviewed a total of 382 papers published between January 2007 and March 2013, then analyzed and categorized to construct a useful foundation of past research.

"Internet of Things" concept is used by Kevin Ashton in a presentation prepared for Procter & Gamble company for the first time in 1999. Where, the benefits of application RFID technology in the supply chain is sorted and proposed to company (Kutup, 2011).

Many convenience and innovation was emerged with use of RFID in supply chain managemen. In 2003, Wal-Mart begun to use RFID technology in reverse logistics network. He developed a new information system platform for recovery options waste of electronic products (Zhiduan, 2005). Visich et al. (2007) attempted enhancing value recovery with RFID and to implement an RFID enabled closed-loop system.

Kiritsis et al. (2008) proposed models and RFID applications to close the information gap within closed loop supply chains (Ondemir & Gupta, 2014b). Xu et al. (2009) illustrated the use of embedded devices for product life cycle monitoring with a case study from the project of Product lifecycle Management and Information tracking using Smart Embedded systems. Jun et al. (2009) introduced an overall framework for RFID applications in product lifecycle management with definition of a product embedded information device. Gonnuru (2010) proposed an RFID integrated fuzzy based disassembly planning and sequencing model and showed the use of life-cycle information for optimal disassembly decisions (Ondemir & Gupta, 2014b).

Kiritsis (2011) studied intelligent products and product data technologies. Ilgin and Gupta (2011) presented a quantitative assessment of the impact of sensor embedded products on various performance measures of a kanban-controlled disassembly line. They showed that sensor embedded products both provide significant reductions in the total system cost and increase the revenue.

Ondemir et al. (2012) proposed a mixed integer linear programming model which determined how to process each end-of-life product on hand using static and dynamic data obtained by RFID tag and sensors to meet product, component and material demands and minimizing total cost. Gu and Liu (2013) adaptedInternet of Things applications to information management in the reverse logistics. Ultimately, they proposed that accurate and timely information lays the foundation of success for the reverse logistics management. Ondemir and Gupta (2014b) proposed a mixed integer programming model used IoT for minimizing remanufacturing, disassembly, recycling, disposal and storage plans in a demand driven environment. Ondemir and Gupta (2014a) proposed a linear physical programming (LPP) model which determined how to process each end-of-life product on hand using the product life cycle information provided with RFID tag and sensors to meet product, component and material demands based on the remaining life. In the problem modeled as optimization of four goals, The first goal is to optimize the total cost including in disassembly, repair, out procurement, disposal, recycling and holding costs; The second goal is to minimize the number of disposed items; The third goal is to maximize material sales revenue; The fourth goal is to maximize customers' satisfaction level.

3. Problem Definition

Problem is related to a manufacturer met the sales & collection (S&C) center demands with new, repaired and remanufactured products. This manufacturer encloses the factory, distribution center and repair center in CLSC.Closed-loop supply chain network based onthe discussed problem is given in Exhibit 1. The S&C center sales to customers products which are supplied from the manufacturer and collects unused products from customers at the same time. However, itis not considered the exchange between customers and the S&C center in CLSC network design and modeling. End-of-life products in S&C center are purchased at a price according to their value level. In this study, there are three recovery options including repair, complete disassembly and disposal to evaluate returned products. In the repair option, damaged components of product are replaced in repair center and then sent to distribution center to meet demands of the S&C center. Disassembly option is complete disassembly of product that implies the every single components is taken out. Qualified component is sold to S&C center to meet its demand, send to the factory to reuse or disposed according to their value level. Disposal option is when product has not sufficient value level to repair or disassembly disposed directly without undertake any purchase cost and without being any processing.Remanufactured products may includenew components as well as used components.The manufacturer needs to supply new components from the outside to meet the products and components demands and optimize the total production cost or take the right recovery decision for each returned products.

At this stage, IoT is used to provide the product information. Product life cycle information is collected, processed and shared by IoT when company collects return products with different value levels. Manufacturer in closed-loop supply chain network produced smart products placed a DIOT (Device of the Internet of Things), so sensors on DIOT monitor the product duringthe whole life cycle and the product life cycle data. Meanwhile, any changes in product status can be monitored and stored by DIOT. This informations can be obtained by several types of reader device with a unique electronic product code which written RFID tag on each product and every IoT users can get this information when need it. Thus, the remaining value of each returned product can be evaluated and used efficiently.

For each time period, the following questions must be answered.

1) How many components should be obtained from external suppliers per unit time?
2) Which recovery options should be selected for returned products? (repair, disassembled or disposed)
3) Which components of disassembled products should be reused, sold to meet the demand or disposed?

This given based on the life cycle information which is monitored and collected by techniques of IoT.

The assumptions of our problem are given below; 1) There is only one productand it is completely modular and life-cycle informations are known. 2) There is no difference between a new product with recovered product and it can meet demand for the same price. 3) The production capacity is sufficient for all product requirements. 4) All cost and sales price information is known. 5) The demand of S&C center is certain and fulfilled for each period. 6) Returned products contain all components including useless components. 7) The components constituting of the product have component importance weights range from 0-1 so as sum of them to be 1. 8) There aren't stock and stock out.

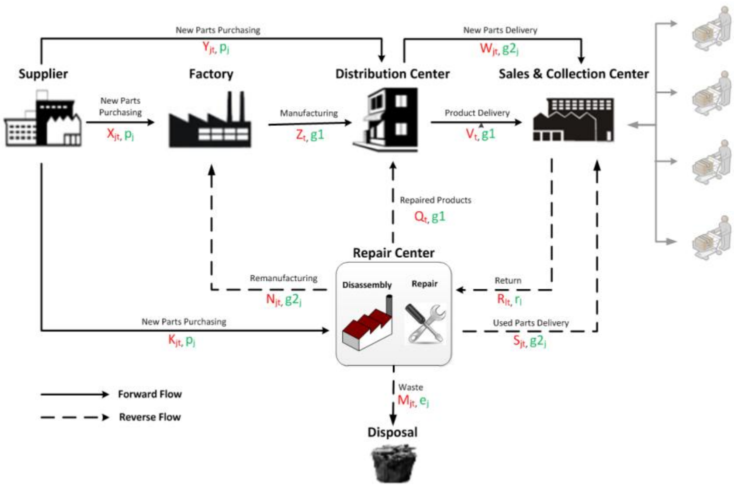

Figure 1. Representational closed loop supply chain network

4. Mathematical Model

Based on the above assumption, a uniform product (automobile, computer, phone, etc.) are determined which is completely modular. The model determines how to process all of returned products to maximize profit for meet the demand. The sets, parameters, decision variables and the model are given as fallows.

<u>Indices</u>

i: *Set of returned products*$(i = 1, 2, \dots, I)$
j: *Set of components*$(j = 1, 2, \dots, J)$
t: *Set of periods*$(t = 1, 2, \dots, T)$
l: *Set of returned product value ranges*$(l = 1, 2, \dots, L)$

Parameters

a_j : *Assembly cost of component j*
d_j : *Disassembly cost of component j*
e_j : *Disposal cost of component j*
f_j : *Refurbishment cost of component j*
$g1$: *Unit transportation cost of product*
$g2_j$: *Unit transportation cost of component j*
p_j : *Procurement cost of component j from the supplier*
r_l : *Purchasing cost of l-level product from the S&C center*
$h1$:*Sales price of product*
$h2_j$: *Units Sales price of new part j*
$h3_j$: *UnitsSales price of used part j*
rc_j : *j.component number in a product*
rfc_{jt} : *Amount of refurbished component j in period t*
bro_{ijt} : *1 if component j of the returned product i is quality deficit in period t, zero otherwise*
$\bar{a}_{it}$:*1if returned i purchases in period t, zero otherwise*
R_{lt} : *Amount of used product in the l-level are purchased from S&C center in period t*
C_i : *Value level of returned i*
dm_t : *Product demand of the S&C center in period t*
dms_{jt} : *Demand for new part j of the S&C center in period t*
dmc_{jt} : *Demand for used part j of the S&C center in period t*
dem_{it} : *1 if returned i is disassembled in period t, zero otherwise*
rep_{it} : *1 if returned i is repaired in period t, zero otherwise*
Q_t : *Amount of repaired product sending from the repair center to the distribution center in period t*
M_{jt} : *Amount of component j sending from the repair center to the disposal in period t*
K_{jt} : *Amount of new component j procuring from the supplier to the repair center in period t*

How to process of the components is determined according to their value levels. It is provided with binary parameterbro_{ijt}. If component j is value level deficit, bro_{ijt} is equal 1. If component j is value level qualified, bro_{ijt} is equal 0. Accordingly qualified components are refurbished and then reused disqualified components are discarded directly.Where, n is threshold value determined for refurbishing of components.

$$bro_{ijt} = \begin{cases} 1(Disposal) & 0 \le diot_j < n \\ 0(Reused) & diot_j \ge n \end{cases} \quad \forall i \text{ and} 0<n$$

All components value levels ($diot_j$) and importance weights of returned products are known. 3 classes (value ranges) are determined for products value levels ($diot_i$) calculated according to this information. C_i (the product value range) is determined as follows. Where, n_1 and n_2 represents value range limits. Accordingly, information of what recovery process (repair, disassembly, and disposal) will be applied for each returned products is obtained.

$$C_i = \begin{cases} \mathbf{1}(Disposal) & 0 \le diot_i < n_\mathbf{1} \\ \mathbf{2}(Disassembly) n_\mathbf{1} \le diot_i < n_\mathbf{2} \\ \mathbf{3}(Repair) diot_i \ge n_\mathbf{2} \end{cases}$$

$\forall i$ and $0<n_1<n_2$ (Ondemir & Gupta, 2014b)

If returned product is purchased in period t and 3.value range, it is repaired. Therefore;

$$rep_{it} = 1, \text{if} \quad C_i . \bar{a}_{it} = 3$$

If returned product is purchased in period t and 2.value range, it is disassembled. Therefore;

$dem_{it} = 1, \quad \text{if } C_i . \bar{a}_{it} = 2$

If returned product is 1.value range, it is discarded directly. Therefore;

$\sum_t dem_{it} + rep_{it} = 0 , \quad \text{if} C_i = 1$

The total amount of the component refurbished after disassembly (rfc_{jt}) is calculated as follows.

$$rfc_{jt} = \sum_{\{i \epsilon I \mid \bar{a}_{it} = 1\}} dem_{it} . \left(1 - bro_{ijt}\right)$$

The amount of products repaired in repair center must be equal to the amount of repaired products sent to distribution center from repair center for product demand fulfillment.

$$Q_t = \sum_i rep_{it} \; \forall t$$

Repaired products are obtained by replacing without an adequate level component in returned products with new parts procured from suppliers. Therefore, new part as the amount of inadequate level components disassembled in repair must be provided to repair center from supplier.

$K_{jt} = \sum_i bro_{ijt} . rep_{it} \; \forall j, t$

Value level deficit components occured during repair and disassembly processes are sent to the disposal center. Therefore, total amount of waste sent to disposal center must be equal to the amount of components are value level deficit.

$M_{jt} = \sum_i bro_{ijt} . (dem_{it} + rep_{it}) \; \forall j, t$

The product value level ($diot_i$)is calculated according to the component value levels($diot_j$)and $component\ importance\ weights$ as follows.

$$diot_i = \sum (diot_j \; x \; Component \; importance \; weights)$$

Decision Variables

X_{jt} : Amount of new component j procuring from the supplier to the factory in period t
Y_{jt} : Amount of new component j procuring from the supplier to the distribution center in period t
Z_t : Amount of product sending from the factory to the distribution center in period t
W_{jt} : *Amount of new component j delivering from the distribution center to the* S&C *center in period t*
V_t : *Amount of product delivering from the distribution center to the* S&C *center in period t*
S_{jt} : *Amount of used part j delivering from the repair center to the* S&C *center in period t*
N_{jt} : *Amount of refurbished component j sending from the repair center to the factory in period t*
$\bar{b}_{jt}$: *Auxiliary decision variable used to determine value of S_{jt} (takes the value 0 or 1)*

4.1. Objective Function

Objective function is to maximize the total profit, the total profit function can be given as follows:

$$\text{Total Profit} = \text{Total Revenue} - \text{Total Cost} \quad (1)$$

1) Total Revenue (TR): Company can perform three different sales for the final products, new components and used parts. Moreover, some of the parts refurbished after disassembly are sent to the factory to remanufacture. These parts can be used instead of new parts and aren't procured from the suppliers, so this section is also taken to be a revenue item. Therefore, TR is composed of four parts as follows.

$$TR = \sum_t V_t . h1 + \sum_t \sum_j \left(W_{jt} . h2_j + S_{jt} . h3_j + N_{jt} . P_j \right) \quad (2)$$

2) Total Cost (TC): The company is accepted to four different costs including total purchasing cost (TPC), total manufacturing costs (TMC), the total transportation cost (TTC) and total disposal cost (TDC).

$$TC = TPC + TMC + TTC + TDC \quad (3)$$

Each term is described below.

2.1) Total purchasing cost (TPC): TPC is calculated as the sum of two sections; the first section indicates purchasing cost performed to satisfy new components demand of factory and the S&C center, the second section indicates purchasing cost used products from the S&C center.

$$TPC = \sum_j P_j \left(\sum_t (X_{jt} + Y_{jt}) \right) + \sum_l r_l \left(\sum_t R_{lt} \right) \quad (4)$$

2.2) Total manufacturing cost (TMC): Manufacturing process consists of three sections including manufacturing cost in factory (TMC1), repair cost (TMC2) and disassembly cost (TMC3).

$$TMC = TMC1 + TMC2 + TMC3 \quad (5)$$

Some of the parts refurbished after disassembly are returned to the factory. Here, if there are missing parts, they are procured from supplier and remanufacturing is performed. If final products produced by repair and remanufacture aren't meet demand of S&C center fully, new product is produced to meet the remaining demand by procure new parts from supplier.

The manufacturing consists of new and remanufactured products in the factory. This cost is the sum of assembly costs of all components from all products that are to be produced.

$$TMC1 = \sum_j a_j . rc_j \left(\sum_t Z_t \right) \quad (6)$$

Repair is applied to returned products whose value levels are good condition. Repair, e.g. considering for an automobile that requires only simple operations such as replacing the damaged rear view mirror. The repair cost should reflect the cost of disassembling for damaged parts, purchasing and assembly cost for new parts.

$$TMC2 = \sum_i \sum_j \sum_t (d_j + a_j + p_j) bro_{ijt} . rep_{it} \quad (7)$$

Complete disassembly is applied to returned products that aren't enough value level for repair but whose components can be reused. Reusable components are refurbished and then sent to the S&C center for meet the demand according to their value level. The remaining parts are sent to the factory for reuse after meet demand of the S&C center. Unusable parts which are in poor condition are discarded. The cost of happening here is the sum of disassembly costs of all components and refurbishig costs of all parts which are in good condition from all products that are to be disassembled.

$$\text{TMC3}= \sum_i dem_{it} (\sum_j d_j + \sum_t f_j \,.\, (1 - bro_{ijt})) \quad (8)$$

2.3) Total transportation cost (TTC): Transportation is dealt with on the basis of products and parts in the model. Final product transportation costs performed to distribution center from factory, distribution center from the repair center and the S&C center from the distribution center are considered equal. In addition, part transportation costs performed to repair center from factory, S&C center from repair center and S&C center from distribution center are also considered to be equal. Accordingly, total transportation cost is calculated as follows.

$$\text{TTC}= \sum_t g1(Z_t + Q_t + V_t) + \sum_j \sum_t g2_j \left(N_{jt} + W_{jt} + S_{jt}\right) \quad (9)$$

2.4) Total disposal cost (TDC): Unusable components occur in repair and disassembly process. Value level deficit components which will be replaced in repair and which will not be refurbished in disassembly are considered to be disposal and its cost is calculated as follows.

$$\text{TDC}= \sum_j \sum_t e_j M_{jt} \quad (10)$$

4.2. Constraints

The amount of new components incoming to distribution center from factory must be equal to the amount of the new components outgoing to S&C center from distribution center. Therefore;

$$Y_{jt} - W_{jt} = 0 \qquad \forall j,t \quad (11)$$

The amount of products incoming to distribution center from factory and the repair center must be equal to the amount of products outgoing to S&C center from distribution center. Therefore;

$$Z_t + Q_t - V_t = 0 \qquad \forall t \quad (12)$$

Some of the components refurbished to be reused after disassembly are sent to S&C center for used part demand fulfillment. As for others, they are sent to factory to be used in remanufacture. Therefore, the amount of component refurbished after disassembly must be equal to the amount of the component to factory and S&C center from repair center.

$$rfc_{jt} - (N_{jt} + S_{jt}) = 0 \qquad \forall j,t \quad (13)$$

Some of the components used manufacturing in factory are met by repair center, the others are met by supplier. Therefore, sum of the components procured factory must meet component requirements of factory.

$$(X_{jt} + N_{jt}) - rc_j . Z_t = 0 \qquad \forall j, t \tag{14}$$

Product demand of the S&C center is provided with final product in distribution center. Therefore, the amount of products sent to the S&C center from distribution center must be equal to products demand of S&C.

$$V_t = dm_t \forall t \tag{15}$$

The S&C center has two different component demands including new and usedparts. The amount of new parts forwarded to the S&C center from the distribution center must be at least equal to new parts demand. When company couldn't meet used part demand completely, remaining part can be completed with new part. Thus, related constraints are formulated as follows.

$$W_{jt} \geq dms_{jt} \forall j, t \tag{16}$$

$$S_{jt} + W_{jt} = dms_{jt} + dmc_{jt} \forall j, t \tag{17}$$

Some of the components refurbished after disassembly are sent to S&C center for used part demand fulfillment. As for others, they are forwarded to factory to remanufacture. The following constraint provides to give priority to the amount of used part sent to S&C centers (S_{jt})in distribution of refurbished components for used part demand fulfillment. Therefore, the amount of used part must be as either total amount of refurbished components after the disassembly or used part demand.

$$S_{jt} = rfc_{jt} . ƀ_{jt} + dmc_{jt} . (1 - ƀ_{jt}) \forall j, t \tag{18}$$

4.3. Numerical Example

The planning model was made in terms of two periods. It is assumed that 6 returned product (i) come at each time period. Each product is made of 5 components A to E. Unit product cost of transportation ($g1$) and product sales price ($h1$) were considered as 0.5 $ and 100 $ respectively. Product demand is 7 for each unit of time. Information on products and components are provided by IoT system. Other parameters are given in Table 1-5.

Table 1. *Otherparameters of numericalexample*

Components	A	B	C	D	E
a_j	1	5	3	2	4
d_j	0.5	1.5	1	0.3	0.8
e_j	0.6	0.2	1	1.5	2
f_j	1.5	2	0.5	1	2
$g2_j$	0.1	0.1	0.2	0.1	0.3
p_j	10	10	5	5	10
$h2_j$	12	12	7	7	12
$h3_j$	6	6	2	3	5
rc_j	1	1	4	2	1

Table 2. *The demand values related to components*

	New part demand (dms_{jt})		Used part demand (dmc_{jt})	
Component	Period 1	Period 2	Period 1	Period 2
A	5	1	3	2
B	4	2	1	3
C	8	4	0	4
D	1	3	1	2
E	6	3	8	3

Table 3. *Value levels and importance weights of components*

Period (t)	Product (i)	Component valuelevel ($diot_j$)				
		A	B	C	D	E
1	1	10	5	3	6	3
	2	10	9	7	8	3
	3	8	1	4	1	0
	4	3	4	1	0	6
	5	2	0	3	3	9
	6	10	7	3	9	8
2	7	2	7	10	3	9
	8	10	3	4	1	7
	9	9	10	5	8	4
	10	2	10	5	10	4
	11	7	8	10	1	3
	12	5	0	10	4	4
Component importanceweight		0.2	0.26	0.08	0.16	0.3

Table 4. *Purchasing costs according to product value range (r_l) and the amount of product purchased related to periods (R_{lt})*

		Product valuelevel($\boldsymbol{l}$)		
	Period(t)	1	2	3
R_{lt}	1	3	1	2
	2	1	5	0
	$\boldsymbol{r_l}$	0	20	50

Table 5. *Value levels ($diot_i$) and value ranges (l) of products*

i	$diot_i$	l
1	5.4	2
2	7.08	3
3	2.34	1
4	3.52	1
5	3.82	1
6	7.9	3
7	6.2	2
8	5.02	2
9	6	2
10	6.2	2
11	5.34	2
12	3.64	1

The data in Table 5 was obtained using value levels and importance weights of component in Table 3. Here, value range limits of product and refurbishing threshold value of component was adopted $n_1 = 4$, $n_2 = 7$ and $n = 4$respectively.

4.4. Solution

Mixed integer linear programming model developed in accordance with these data was solved in GAMS/CPLEX 23.3 software package, the following results were obtained.

Table 6. *The optimal objective function value*

Objective Function	Value
TR	1993
TC	1725.50
TPC	1295
TMC	389.90
TMC1	312
TMC2	*23.80*
TMC3	54.10
TTC	26.70
TDC	13.90
Z	*267.50*

Table 7. *The process detail of returned products*

	Time period	
Process	1	2
Repair	2 (2, 6)	0
Disassembly	1(1)	5(7, 8, 9, 10,11)
Disposal	3(3, 4, 5)	1(12)

Table 8. *The flow detail of products*

Time period	Z_t	V_t	Q_t
1	5	7	2
2	7	7	0

According to the solution results given in Table 6; the total revenue is 1993 $, the total cost is 1725.50 $ and the optimal objective function value maximized profit is 267.50 $. Exhibit8 gives process details applied to purchased product. Accordingly first period, products 2 and 6 have to be repaired and product 1 has to be disassembled. As for products 3, 4 and 5, they have to be discarded because of can not reused.

Table 9. *The process detail of components*

	Period 1							Period 2						
Component	X_{jt}	Y_{jt}	W_{jt}	S_{jt}	N_{jt}	M_{jt}	K_{jt}	X_{jt}	Y_{jt}	W_{jt}	S_{jt}	N_{jt}	M_{jt}	K_{jt}
A	5	7	7	1	0	0	0	6	1	1	2	1	2	0
B	5	4	4	1	0	0	0	6	2	2	3	1	1	0
C	20	8	8	0	0	2	1	27	4	4	4	1	0	0
D	10	1	1	1	0	0	0	14	3	3	2	0	3	0
E	5	14	14	0	0	2	1	6	3	3	3	1	1	0

Product demand which is 7 in first period is met with 2 repaired and 5 newproducts. The second period, all demands are met with new product because of there is no product be repaired (Table 8). According to Table 9, total of 12 in first period (5 component A are procured to factory from supplier and 7 component A are procured to distribution center from supplier).

Seven component are sent to distribution center from supplier; five of them met new part demand and two of them met remaining used part demand due to there aren't adequate amount of used part. The optimal distribution networks belonging to the first and second periods are given in Figure 3 and 4 respectively.

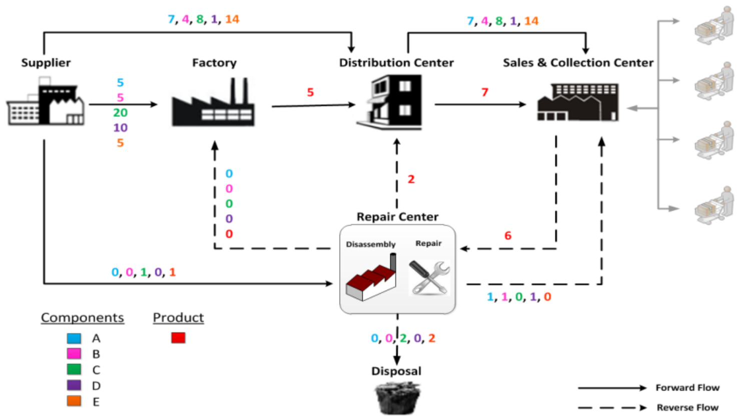

Figure 3. *Optimal flow at firstperiod*

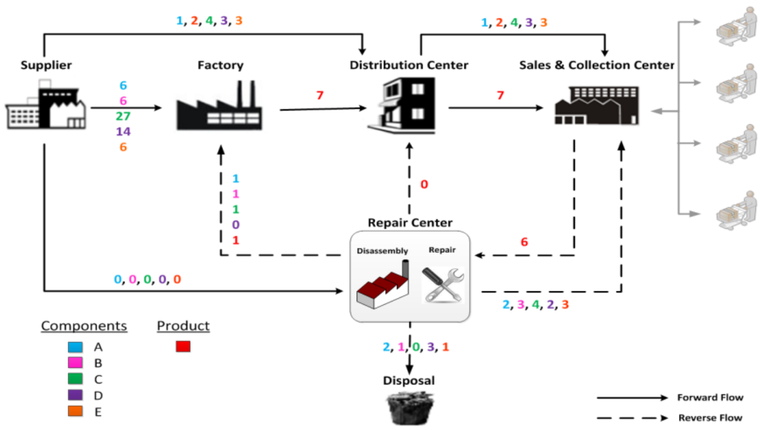

Figure 4. *Optimal flow at second period*

5. Experimental Studies

The first stage of this section is aimed to test the performance of the proposed model and investigate the impact of some parameter changes on model. For this reason, 36 combinations are considered that number of components and periods are 5-10-20, value levels $(diot_j)$ of components in returned products according to binomial distribution are2-4-6-8 (B(10, p), p(0.2-0.4-0.6-0.8)). A total of 360 test problems are produced to be 10 samples from each combination and solved using GAMS package program.

The solution results of these test problems are summarized according to each components, periods and diot levels as the average objective function, revenue, cost values and solution times in Table 10, 11 and 12.

Table 10. *Profit, revenue, costand solution time values according to number of components*

Number of Component	OBJ (Profit)	OBJ1 (Revenue)	OBJ2 (Cost)	CPU Second
5	750301.74	1108009.61	357707.87	0.039
10	664774.58	1349042.17	684267.59	0.041
20	485434.29	1829945.98	1344511.69	0.045

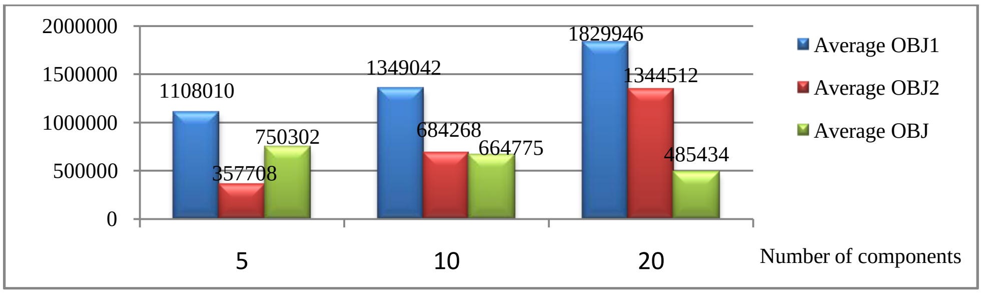

Figure 5. *Effect of number of components on objective functions*

It is observed that the total revenue and cost increases by the number of components increase in Figure 5. But the total profit has decreased because the increase rate of cost is greater than revenue. This case gives the result that recycling costs will increase and therefore profit will decrease by the complexity of product increase in CLSC.

Tablo 11. *Representational closed loop supply chain network*

Number of Period	Profit per Period	Revenueper Period	Costper Period	CPU Second
5	54666.57	122668.78	68002.21	0.039
10	54675.38	121466.87	66791.49	0.041
20	54021.20	122949.26	68928.06	0.045

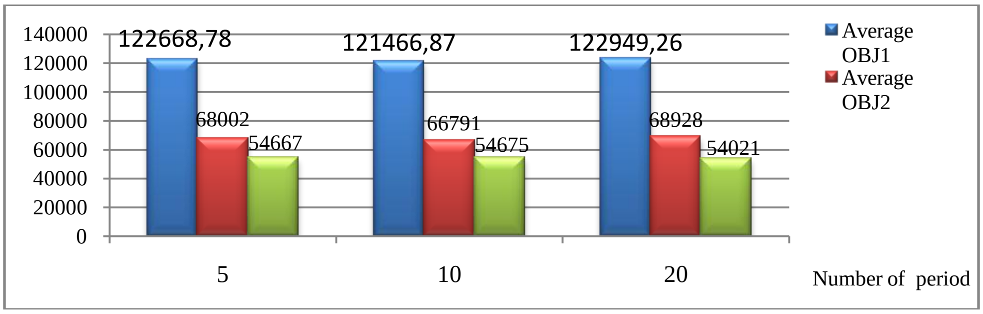

Figure 6. *Effect of number of periyods on objective functions*

Figure 6 shows that the change in the number of period has no influence on the profit, revenue and cost on the basis of period. This case indicates that the system is stabilized.

Table 12. *Profit, revenue, costandsolution time values according to component diotlevels*

Diotlevel	OBJ(Profit)	OBJ1(Revenue)	OBJ2(Cost)	CPU Second
0.2	568690.42	1451677.54	882987.12	0.041
0.4	568752.10	1423502.12	854750.03	0.043
0.6	576201.77	1395315.93	819114.16	0.042
0.8	820369.87	1445501.41	625131.54	0.042

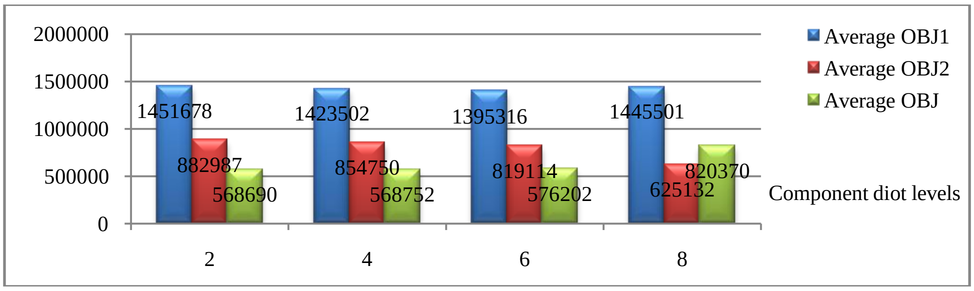

Figure 7. *Effect of componentdiotlevels on objective functions*

As expected, an increase is observed on profit by the component diot level increases since returned products can be reused at a lower cost in Figure 7.

The product operation details according to varying component diot levels are shown in Figure 8. According to this exhibit; it is seen that almost all of the products whose component diot levels are average 0.2 are disposed, about 50% products whose component diot levels are average 0.4 are disassembled and about 50% them are also disposed, about 4% products whose component diot levels are average 0.6 are repaired and about 96% them are also disassembled and about 98% products whose component diot levels are average 0.8 are repaired and about 2% them are also disassembled. This proves that the model works as expected.

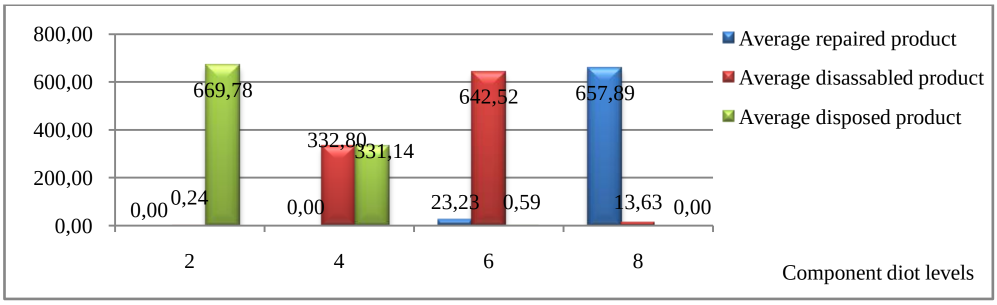

Figure 8. *Process details according to component diotlevels*

In the next stage, it is aimed to analyze independent variables that are number of components, number of periods and value level of components ($diot_j$) interact between them and their impact on the dependent variable that is profit. For this, vanyans analysis was performed using profit values basis of period obtained according to number of components, number of periods and value level of components ($diot_j$) from the solition results of test problems. Variance analysis results are presented in Table 13-16 summarily.

Table 13. *Analysis of variance table obtained SPSS*

Tests of Between-Subjects Effects

Dependent Variable: Profit

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	75897859885,079[a]	35	2168510282,431	63,478	,000
Intercept	1067500785314,263	1	1067500785314,263	31248,343	,000
component_numbers	32587288891,019	2	16293644445,509	476,955	,000
diot_levels	31734672473,188	3	10578224157,729	309,650	,000
period_numbers	33782092,450	2	16891046,225	,494	,610
component_numbers * diot_levels	10940746810,656	6	1823457801,776	53,377	,000
component_numbers * period_numbers	138449116,179	4	34612279,045	1,013	,401
diot_levels * period_numbers	237604657,371	6	39600776,229	1,159	,328
component_numbers * diot_levels * period_numbers	225315844,217	12	18776320,351	,550	,881
Error	11068434857,954	324	34161835,981		
Total	1154467080057,287	360			
Corrected Total	86966294743,033	359			

Note: a. R Squared = ,873 (Adjusted R Squared = ,859)

As can be seen from Table 13, the difference between number of components, value level of components ($diot_j$) and interaction of $diot_j$ with number of components is statistically significant in the result of variance analysis which made in order to determine whether number of components, number of periods and $diot_j$ show a significant difference on the objective function ($p < 0.05$). But the difference between the number of periods and its all other interactions isn't significant ($p > 0.05$). After this process, complementary post-hoc analysis techniques are passed on to determine which groups result from significant differences detected after variance analysis.

Table 14. *Levene's Test relating to equality of variances*[a]

Dependent Variable: Profit

F	df1	df2	Sig.
1,278	35	324	,142

Notes: Tests the null hypothesis that the error variance of the dependent variable is equal across groups. (a). Design: Intercept + component_numbers + diot_levels + period_numbers + component_numbers * diot_levels + component_numbers * period_numbers + diot_levels * period_numbers + component_numbers * diot_levels * period_numbers

After variance analysis, the hypothesis that whether variances of group distributions are homogeneous is tested by Levene's test for decides to which post-hoc multiple comparisons techniques will use. Table 14 shows the Levene's test results. According to these results, it is seen that there isn't difference between variances of groups, so they are homogeneous. Therefore, Tukey multiple comparison technique used commonly when variances are homogeneous is preferred.

Table 15. *Tukey Test Homogeneous Subsets relating to number of components*

Tukey HSD Profit

component_numbers	N	Subset		
		1	2	3
K20	120	41811,0962		
K10	120		56789,6988	
K5	120			64762,3576
Sig.		1,000	1,000	1,000

Notes: Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square (Error) = 34161835,981. (a) Uses Harmonic Mean Sample Size = 120,000. (b) Alpha = ,05.

The difference between all component groups is significant in the tukey test relating to number of components given in Table 15 (p <0.01). The groups are listed in order of ascending means. Theprofit values that are under different subset indicate that there is a statistically significant difference between them. As can be seen objective function value reduced as long as number of components increases. This case proves statistically the result that recycling costs will increase and therefore profit will decrease by the complexity of product increase in CLSC as we get the result of test problems.

Table 16. *Tukey Test Homogeneous Subsets relating to value level of components* $(diot_j)$

Tukey HSD Profit

diot_levels	N	Subset	
		1	2
2	90	48734,2953	
4	90	48748,5838	
6	90	49630,3363	
8	90		70704,3214
Sig.		,733	1,000

Notes: Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square(Error) = 34161835,981. (a) Uses Harmonic Mean Sample Size = 90,000. (b) Alpha = ,05.

The difference between groups of 2-4-6 $diot_j$ has not been significant (p > 0.05), but a statistically significant difference between profit values of 8 $diot_j$ with other groups has been detected (p <0.05) in Table 16. Therefore, profit values of 2-

4-6 $diot_j$ and 8 $diot_j$ are different subsets. An increase is observed on profit as expected, by value level of components increases.

6. Conclusion

The businesses working to adapt changing life conditions resort to improvement its supply chain to provide the most effective service to its customers by taking into consideration polluted environment, decreasing natural resources day by day and state regulations. At the same time, social and economic level of achievements in this context to get the business, the necessity of CLSC design is increasing. But the design of CLSC network is more complex than traditional supply chain network. It quite complicates the design stage to be connected to uncertainties of decisions such as determining to what amount products will be collected from customers, will be classified according to what of deformation range in the product, determining to optimal improvement process to recovered product, in addition to delivering products to customer. At this stage, IoT system reduces related uncertainty by providing all life information of returned product and substantially mitigates planning of reverse flow activities. So that increase of things produced their data on their own will bring a more reliable knowledge accumulation, reduce losses, avoid waste and also reduce costs pursue it.

In this study, a closed-loop supply chain network met the S&C center demands with new, repaired and remanufactured products was considered. Manufacturer on the network is manufacture an intelligent product placed diot and thereby can follow to product during its all life cycle. System is arranged to be applied of three different recovery options including repair, complete disassembly and disposal to evaluate returned.A mixed integer linear programming model is proposed for a single type of product is completely modular (automobile, computer, telephone, etc.). The model meets products and components demands of customer based period, maximizes profit consist of different sales revenues and total cost (total production, purchase, transportation and disposal costs) and determines how to evaluate all returned products.

The proposed model are solved with the aid of a numerical example using GAMS 23.3/CPLEX on a personal computer with an Intel® Core™ i3 CPU processor with a speed of 2.13 GHz and 4GB RAM.The testing problems are produced to test the operability of the developed models and to see the impact of some parameter changes on the model and the inferences obtained from their solution results are interpreted.Later, vanyans analysis is performed using profit values basis of period obtained from the solition results of the test problems to analyze independent variables that are number of components, number of periods and value level of components interact between them and their impact on the dependent variable that is profit.

For future research, the proposed model could be applied in business performed CLSC activities and developed on networks with multi-product, more product recovery options and fixed costs to be more realistic. Also uncertainties in product returns could be added as fuzzy to network structure.

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