Modeling Sustainable Truck Rental Operations Using Closed-Loop Supply Chain Network

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Abstract—Moving industries consume numerous resources and dispose masses of used packaging materials. Proper sorting, recycling and disposing the packaging materials is necessary to avoid a sever pollution disaster. This research paper presents a conceptual model to propose sustainable truck rental operations instead of the regular one. An optimization model was developed to select the locations of truck rental centers, collection sites, maintenance and repair sites, and identify the rental fees to be charged for all routes that maximize the total closed supply chain profits. Fixed costs of vehicle purchasing, costs of constructing collection centers and repair centers, as well as the fixed costs paid to use disposal and recycling centers are considered. Operating costs include the truck maintenance, repair costs as well as the cost of recycling and disposing the packing materials, and the costs of relocating the truck are presented in the model. A mixed integer model is developed followed by a simulation model to examine the factors affecting the operation of the model.

Keywords—Modeling, truck rental, supply chains management, simulation.

I. INTRODUCTION

THE research on closed loop supply chain and reverse logistics has received vital attention from current researchers due to the growing impact of wastes of human and animal that are sometimes classified as hazardous on environment and human health. The closed-loop supply chain assumes the responsibility of both forward and reverse supply chains' activities throughout the product life-cycle. It manages the forward flow of materials through suppliers, manufacturers, distributers and retailers. It, then, manages the return flow that will undergo examination at collection centers to be directed to the distributer for resale if in good condition; repair centers and resale as refurbished products; manufacturers, or for disposal. Typical types of return include commercial returns, repair/warranty returns, leasing returns, end of use returns and end of life returns.

The shipping industry consumes several types of packaging materials. The world consumption rate of packaging materials is immense. According to [1], the forecast of marketing research published regarding current and future global sales of packaging materials will be $975 billion by 2018. Due to the stupendous forecast of costs, this research intends to create sustainable truck-rental operations, decreasing shipping costs, efficient use of packaging material, saving environmental

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land-fills and resources. According to [2], from one fourth to one third of the domestic waste are packaging materials. Some of the packaging materials are recyclable such as recycling boxes, drink cartons, returnable glass bottles, plastic and aluminum drink cans, while other packaging materials are not recyclable such as contaminated plastic with food, packets made of several layers of cardboards, plastic and foil of fruit juice cartons.

This research proposes a conceptual model for sustainable truck rental operations using the closed-loop supply chain network. Mixed integer programming and simulation models were developed to optimize the system performance.

II. LITERATURE REVIEW

The authors of [3] presented the definition of [4] of the secondary packaging as the packaging materials used to package the products shipped from the sender to the receiver either in industry or in retail. Those materials include cardboard boxes, ballets, containers, slip sheets, etc. Some of those materials are used one time, and the others are returnable. They also presented [5]'s division of the systems with return logistics and the one without. The systems with return logistics are:

a. Transfer System. In this case, the sender is responsible for tracking the containers until they reach the destination, including cleaning, maintaining, and storing them. The transfer system is only responsible for returning the containers from destination to the shipper.

b. Depot System. The author of [5] presented two types of depot systems:

1. Book system. In this case, the shipper has an account with the central agency responsible for the containers. When the shipper receives the containers, the shipper's account will be debited by the number of containers received. When the shipment reaches destination, the receiver's account will be debited, and the shipper's account will be credited. The central agency will have full control of the container's flow.

2. Deposit system. In this system, the shipper pays a deposit on each container that they received and debits his/her recipient with the same amount. When the recipient returns the containers to the agency, he/she will be refunded with the deposit.

There is another system that does not use return logistics. In this system, the sender rents the container and is fully responsible for them. Whenever the sender finishes, he/she returns them back to the agency. The sender is fully responsible of all activities involved including cleaning,

maintenance, return logistics, and storage.

The authors of [3] considered the application of reverse logistics in the supply chain physical distribution. They considered the deposit system presented in [5]. Their reverse logistics network consists of an agency responsible for renting the containers and the logistic service organization. When a sender rents some containers, he/she contacts the agency that in turns contacts the logistic service organization to distribute the requested containers to the senders from the nearest depot. Once the shipment arrives to the recipient, he/she informs the agency. The agency orders the logistic service organization to collect the containers from the recipients and places them in the nearest container depots. Maintenance and cleaning activities are carried out on the containers before reusing them. Then, containers may be relocated. They presented a linear programming model for the planning of the return logistic system to determine the number of containers needed and number and locations of the container depots. Their objective function was to minimize the total costs of logistics including the costs of distribution, collection, relocation, as well as the fixed cost of establishing container depots.

The authors of [6] developed an optimization model for a closed loop supply chain. The proposed network includes demand locations, manufacturers, and collection centers. The manufacturers can produce products from the available raw materials as well as they can recycle the returned products. Collection centers inspect the returned products to sort those that could be fixed from already lost ones. Those that can be fixed are, then, sent to their manufacturers to restore and those that cannot are disposed. The objective is to identify the location and capacity of each production plant, each collection site leading to minimum total cost. The costs include production, transportation, collection, fixed costs for opening a production plant, fixed cost for opening a distribution center, and disposal cost. The optimization model includes multiple products and multi period.

The authors of [7] presented a state of the art literature review article for the sustainable rent-based closed-loop supply chain research regarding the fashion products. The textile industry generates much pollution, and due to the short fashion product life cycle, the amount of waste produced had increased and an improper disposal of that waste would make the problem much more severe. They reviewed several research papers regarding the closed-loop supply chain of fashion products including product manufacturing, laundry, logistics, and disposal.

A marketing report was published regarding the current and future global sales of the packaging materials can be found in [1]. The result of the forecast reveals that the annual global demand in 2018 will reach $975 billion. The report also presents the sales distribution based on the sales of 2012 to be 36% for Asia, 23% for North America, 22% for Western Europe, 6% for Eastern Europe, 5% for South and Central America, 3% for the middle east, 2% for Africa, and 2% for Australia from the total sales. The forecast results also reveal that Asia's share is expected to reach 40% by 2018. The report indicated that the growth trend of the sales of packaging

materials is driven by several other trends such as the growth of housing and construction investment, retail chain development, and the living standards. The report suggested minimizing the use of packaging materials, using recyclable packaging, and if convenient, buying dried goods in bulk.

The resource manual [8] divided the automotive waste into three categories: 1) solid waste, 2) liquid waste, and 3) gases waste. The solid waste includes oil filters, fuel filters, air filters, oil containers, cans and glass containers, papers, asbestos, break shoe and pads, scrap metal, lead-acid batteries, tires, aerosol cans, and lamps. The liquid waste is divided into two categories: in vehicle usage and in shop usage such as vehicle engine lubricating oils, transmission fluids, and different construction oils.

III. CONCEPTUAL MODEL

This section presents a conceptual model for a proposed closed-loop supply chain model for the truck rental service. The proposed conceptual model, Fig. 1, shows suppliers A and C that provide the raw-materials necessary for making the packaging materials (cardboard materials, and plastic materials). The raw-materials and the recycled packaging materials are delivered to the manufacturing firms that produce cardboard as well as plastic materials. Supplier B provides the raw-materials necessary for truck manufacturing firms. The truck rental agency purchases the trucks from the truck retailers or distributers. Packaging materials are purchased from the cardboard and plastic packaging materials distributers. The truck rental centers provide trucks and equipment for rent as well as packaging materials for sale to their customers. Demand location "sender" is the customer location who rents the truck and equipment to move its products to the destination location "Receiver". Once the truck arrives at the destination and the customer downloads the materials shipped at the destination location, the customer returns the truck to the closest collection center. The collected trucks will be cleaned at the collection center and the used packaging materials are sorted to recyclable cardboard materials, recyclable plastic materials, and materials that are not recyclable. The recyclable cardboard materials and plastic materials will be shipped to the closest cardboard materials recycling center and plastic materials recycling center. The other materials are shipped to the closest disposal site. The trucks are routed to the closest maintenance and repair facility. The repair center performs preventive maintenance and repair to the trucks as needed. It will sort the used truck parts and scarps to recyclable and non-recyclable. The recyclable materials are shipped to the closest recycling center, and the others will be shipped to the closest disposal site.

IV. OPTIMIZATION MODEL

This section presents the proposed optimization model of the truck rental case using the closed loop supply chain network. The objective of the mathematical model is to identify the optimal locations of the truck rental offices, truck collection centers, truck repair centers, and the disposal

centers. The following are some of the notation used in the construction of the optimization model:
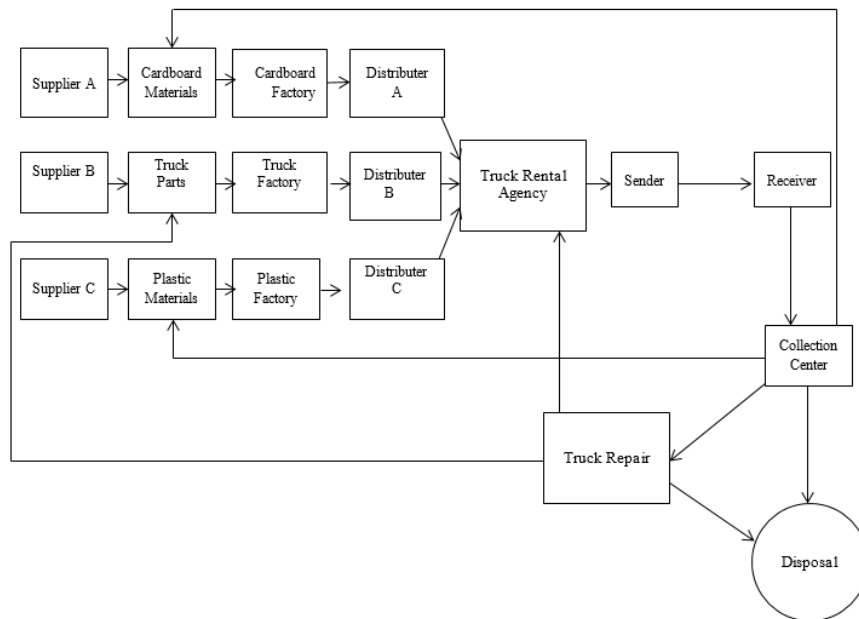

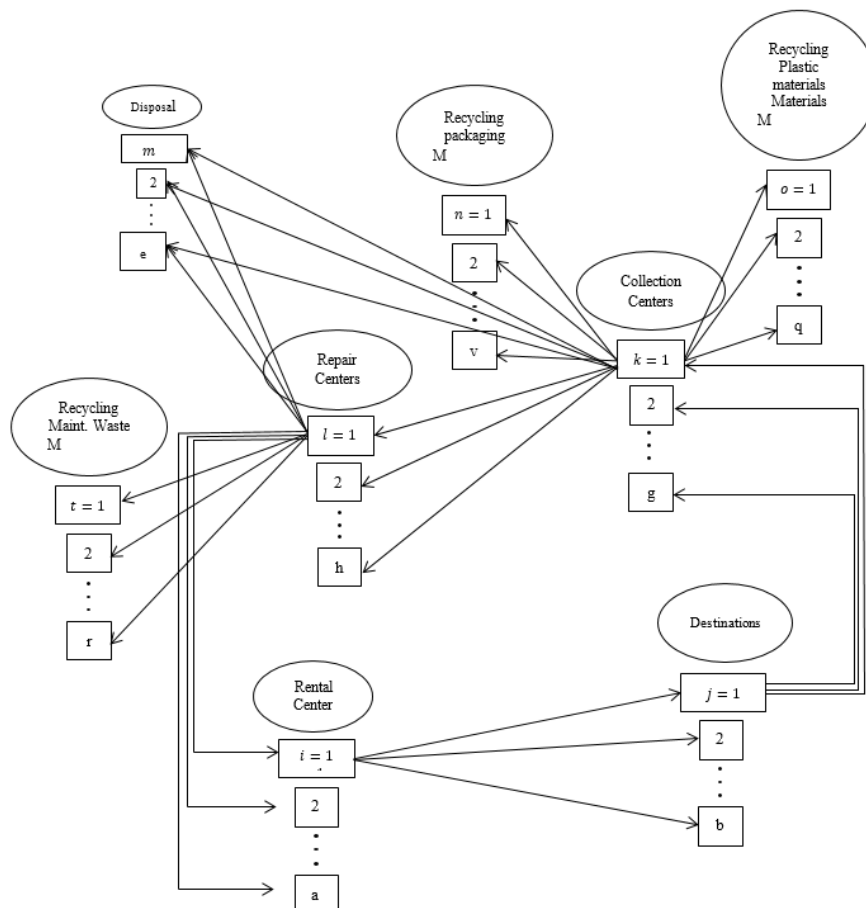Fig. 1 Conceptual Model for the Closed-Loop Supply Chain Model of the Truck Rental Case

Fig. 2 Flows of trucks, package Materials, Disposed and Recycled items

A. Model Parameters and Decision Variable Definitions

This section presents definitions to the parameters as well as the decision variables to be considered when constructing the optimization model.

1. Parameter Definitions

p Number of truck types

y Number of working-days in a year

a Number of potential truck rental centers

b Number of destination locations

g Number of potential truck collection centers

h Number of potential truck maintenance and repair centers

e Number of disposal sites

v Number of cardboard recycling sites

q Number of plastic recycling sites

r Number of maintenance waste recycling sites

cp Generated fund per ton of recycled cardboard packaging materials

cl Generated fund per ton of recycling plastic materials

cw Generated fund per ton of recycling maintenance waste

2. Cost/Revenue Definitions

i. Fixed Costs

PC^u Cost of purchasing a truck of type u

FR_i Annual fixed cost required to construct the ith rental facility, i=1,2,...,a.

FC_k Annual fixed cost required to construct the kth collection facility, $k = 1, 2, ..., g..$

FM_l Annual fixed cost required to construct the lth maintenance and repair facility, l=1,2,...,h.

FD_l Annual fixed cost required to use the mth disposal facility, $m = 1, 2, ..., e.$

ii. Variable Cost Parameters

C'^{ru}_{kl} Cost of moving a truck of type u from the collection center k to the maintenance center $l, u = 1, 2, ..., p$

C''^{ru}_{li} Cost of moving a truck of type u from the maintenance center l to the rental center i

C'_{km} Cost per ton of disposing packaging and plastic materials from the collection center k to the disposal site m

C''_{lm} Cost per ton of disposing truck maintenance waste from the repair center l to the disposal site m

iii. Revenue Generated Parameters

Rp^u_{kn} Revenue generated for recycling a type u truck-load of packaging materials from the collection center k to the recycling site n

Rl^u_{ko} Revenue generated for recycling a type u truck-load of plastic materials from the collection center k to the recycling site o

RW^u_{lt} Revenue generated for recycling a type u truck-load of maintenance waste from the repair center l to the recycling site t

iv. Capacity Parameters

CR^u_i Capacity in terms of the annual number of trips of rental center i of type u trucks

CC^u_k Capacity of collection center k of type u trucks

CM^u_l Capacity of repair/maintenance center l of type u trucks

CD_l The lth disposal center capacity in tons (or volume)

CRP_n The zth recycling center capacity for packaging materials in tons or volume, $n = 1, 2, ..., v..$

CRM_o The oth recycling center capacity of plastics materials in tons or volume, $o = 1, 2, ..., q.$

CRW_t The tth recycling center capacity of maintenance waste in tons or volume, $t = 1, 2, ..., m..$

v. Demand Parameters

D^u_{ij} Expected annual trips from the sender i to the destination j for each truck of type u

vi. Other Parameters

$DPack^u$ Expected amount of disposed packaging materials from type u truck in tons (or unit volume)

$DPlastic^u$ Expected amount of disposed plastic materials from type u truck in tons (or unit volume)

$DPart^u$ Expected amount of disposed maintenance materials and parts from each type u truck in tons (or unit volume)

$Rpack^u$ Expected amount of recycled packaging materials from type u truck in tons (or unit volume)

$Rplastic^u$ Expected amount of recycled packaging materials from type u truck in tons (or unit volume)

$Rwaste^u$ Expected amount of recycled maintenance materials from type u truck in tons (or unit volume)

CT^u_{ij} Contract Time (days) for the truck rentals from rental office i to the receiver j for a truck of type u.

RT^u_{ji} Return Time (days) from the destination j to the rental center i for a truck of type u.

vii. Decision Variables

X^u_{ij} Expected annual trips from destination i to truck collection center j for each truck of type u.

S^u_{ij} Expected annual trips from the truck collection center i to truck maintenance and repair center j for each truck of type u.

RC^u_{ij} Truck rental charge for type u trucks to travel from sender o to the destination q.

R^u_{li} Number of trips of trucks of type u to be relocated annually from the maintenance center l to rental center location i.

E^u_{jk} Number of trucks of type u to be relocated annually from customer destination j to the collection center j.

BR^u_i Binary variable = 1 if location i is to be considered as a rental center for truck of type u and 0 otherwise.

BC^u_k Binary variable = 1 if location k is to be considered as a collection center and 0 otherwise.

BM^u_l Binary variable = 1 if location l is to be considered as a maintenance/repair center and 0 otherwise.

BD_m Binary variable = 1 if location m is to be considered as a disposal site and 0 otherwise.

BRW_t Binary variable = 1 if location t is to be considered as a recycling site for maintenance waste materials and 0

otherwise

BRP_h Binary variable = 1 if location n is to be considered as a recycling site for packaging materials and 0 otherwise

BRl_o Binary variable = 1 if location o is to be considered as a recycling site for plastic materials and 0 otherwise

B. Model Constraints

1. Capacity Constraints

Those constraints are to be stated for all $u = 1, 2, \dots , \; p$.

The total number of trucks of type u to be relocated annually from maintenance center l to rental center location i is bounded by its capacity.

$$R_{l1}^u + R_{l2}^u + R_{l3}^u + \dots + R_{la}^u \leq BM_l^u CM_l^u \text{ for all } l = 1, 2, \dots, h.$$

The summation of the expected annual demand in terms of trips from truck rental center i to all destination for a truck of type u is bounded by the capacity of that center

$$D_{i1}^u + D_{i2}^u + D_{i3}^u + \dots + D_{ib}^u \leq BR_i^u CR_i^u \text{ for all } i = 1, 2, \dots, a.$$

The summation of the expected annual trips from truck collection center k to truck maintenance and repair center j for a truck of type u is bounded by the capacity of collection center k of type u trucks

$$S_{k1}^u + S_{k2}^u + S_{k3}^u + \dots + S_{kh}^u \leq BC_k^u CC_k^u \text{ for all } k = 1, 2, \dots, g.$$

The disposed material plastic, packing, and plastic material is less than the disposing site

$$(Dpack^u + Dplastic^u) \sum_{u=1}^{p}(D_{1m}^u + D_{2m}^u + \dots + D_{gm}^u) + Dpart^u \sum_{u=1}^{p}(D_{1m}^u + D_{2m}^u + \dots + D_{hm}^u) \leq CD_m \, BD_m \text{ for all } m = 1, 2, \dots, e.$$

The recyclable packaging material is less than the capacity in terms of the annual number of trips of rental center

$$Rpack^u \sum_{u=1}^{p}(R_{1n}^u + R_{2n}^u + \dots + R_{gn}^u) \leq CR_n^u \, BRP_n \text{ for all } n = 1, 2, \dots, v.$$

The recyclable plastic material is less than the capacity in terms of the annual number of trips of rental center

$$Rplastic^u \sum_{u=1}^{p}(R_{1o}^u + R_{2o}^u + \dots + R_{go}^u) \leq CR_o^u \, BRL_o \text{ for all } o = 1, 2, \dots, v.$$

2. Balance Constraints

The following are the balance constraints required for the model:

Number of trips to a sender is equal to the number of delivery trips coming out

$$R_{1i}^u + R_{2i}^u + \dots + R_{hi}^u = D_{i1}^u + D_{i2}^u + \dots + D_{ib}^u, \quad \text{for all} \quad i = 1, 2, \dots, a$$

The number of delivery trips to a certain node is equal to the number of the trips to the collection center, it could be easily adjusted to a certain percentage if required instead of being equal

$$D_{1j}^u + D_{2j}^u + \dots + D_{aj}^u = X_{j1}^u + X_{j2}^u + \dots + X_{jg}^u, \quad \text{for all} \quad j = 1, 2, \dots, b$$

The number of delivery trips reaching a collection center is equal to the expected annual trips to the maintenance center, it could be adjusted to a certain percentage if the truck does not have to visit the maintenance center each time

$$X_{1k}^u + X_{2k}^u + \dots + X_{bk}^u = S_{k1}^u + S_{k2}^u + \dots + S_{kh}^u, \quad \text{for all} \quad k = 1, 2, \dots, g$$

Total number of expected annual trips from the truck maintenance for trucks of type u is equal to the total number of annual trips from the maintenance center l to all senders

$$S_{1l}^u + S_{2l}^u + \dots + S_{gl}^u = R_{l1}^u + R_{l2}^u + \dots + R_{la}^u, \quad \text{for all} \quad l = 1, 2, \dots, h$$

3. Truck Capacity at Rental Centers

This section determines the trucks type u capacity needed at each rental office i in terms of number of truck miles (or truck km per year)

$$CR_i^u = \sum_{j=1}^{b} D_{ij}^u (CT_{ij}^u + RT_{ji}^u) \text{ for all } u \text{ and } i.$$

Total number of type u trucks is determined as follows for all $u = 1, 2, \dots, p$:

$$\sum_{i=1}^{a} \frac{CR_i^u}{y} = \sum_{i=1}^{a} \frac{\sum_{j=1}^{b} D_{ij}^u (CT_{ij}^u + RT_{ji}^u)}{y}$$

Total fixed truck purchasing costs is determined as follows:

$$\sum_{u=1}^{s} \sum_{i=1}^{a} \frac{\sum_{j=1}^{b} D_{ij}^u (CT_{ij}^u + RT_{ji}^u)}{y} PC^u$$

The annual fixed truck purchasing cost is the total truck cost divided by the life time of a truck

C. Objective Function

This section presents the process of developing an objective function for the mathematical model. The model will maximize the profit function; which is the difference of the revenue and total cost.

$$\text{Max. Profit} = \text{Revenue} - \text{Cost}$$

1. Modeling the Revenue

This section develops the mathematical model determining the revenue generated from the truck rental process. The revenue consists of the fees the customer pays when renting a truck, the fund generated from recycling the packaging materials, and the fund generated from recycling the auto parts as shown below.

Revenue = Truck rental fees + Payments for the recycled

packaging materials + Payments for the recycled truck parts and materials

2. Truck Rental Charges

The annual truck rental charges are modeled as the annual demand on each road (in terms of the annual number of trips) multiplied by the truck rental charge on each associated with each road. Truck annual Rental charges:

$$z_1 = \sum_{u=1}^{p} \sum_{i=1}^{a} \sum_{j=1}^{b} D_{ij}^{u} RC_{ij}^{u}$$

3. Recycling Charges

Recycling charges consists of the fund generated from the recycled packaging materials as well as the ones for the recycled truck parts

Recycling packing materials charges:

$$z_2 = \sum_{u=1}^{p} \sum_{k=1}^{v} \sum_{n=1}^{g} X_{ij}^{u} RP_{kn}^{u} \, Rpack^{u} cp$$

Recycling plastic materials charges:

$$z_3 = \sum_{u=1}^{p} \sum_{k=1}^{v} \sum_{o=1}^{q} X_{ij}^{u} Rl_{ko}^{u} \, Rplastic^{u} cl$$

Recycling Truck parts charges:

$$z_4 = \sum_{u=1}^{p} \sum_{l=1}^{h} \sum_{t=1}^{r} X_{ij}^{u} RW_{lt}^{u} \, Rwaste^{u} cw$$

The revenue objective function is:

$$Revenue = z_1 + z_2 + z_3 + z_4$$

D. Costs Associated with the Rental Company

This section models the different costs associated with the truck rental company. The costs are as follows:

Costs of Disposing the Packaging and Plastic materials

$$\sum_{u=1}^{p} \sum_{k=1}^{v} \sum_{m=1}^{e} D_{km}^{u} \, (DPack^{u} + DPlastic^{u}) \, C'_{km}$$

Costs of Relocating Trucks from Collection to Repair Centers

$$\sum_{u=1}^{p} \sum_{k=1}^{v} \sum_{m=1}^{e} D_{km}^{u} \, C'_{km}$$

Costs of Relocating Trucks from Repair to Rental Centers

$$\sum_{u=1}^{p} \sum_{l=1}^{h} \sum_{i=1}^{a} R_{li}^{u} \, C''_{li}$$

Costs of Disposing the Truck Maintenance

$$\sum_{u=1}^{p} \sum_{l=1}^{h} \sum_{m=1}^{e} DW_{lm}^{u} \, C''_{lm}$$

V. ANALYSIS OF RESULTS

The mixed integer program model is an *NP* hard model because it belongs to the knapsack problem group, and since this research tries to prove the concept of the model discussed here, the methodology selected is simulation to study the characteristics of the problem, and we leave exact solutions to further research.

We consider a renting company that provides rental trucks for senders. The customer (sender) drives the truck to a destination. Senders and receivers are grouped into zones. A movement from a zone to another incurs cost and generates revenue. Whenever a truck arrives at a destination, there are three options: to return the truck back to the depot, to route it to the nearest collection site, or to send the truck to the repair center. There is a cost incurred in the movement of the truck, and recycling shipping recyclable material would generate some revenue.

After going to the collection center, the truck may go to the maintenance center or return to the depot. At the maintenance center, trucks are repaired incurring some costs and generating some money from the recycled parts.

The model was built on a simulation package called ProModel on an intel i3-4200 laptop with 4 GB RAM. We consider a case with 100 orders daily serving three or five zones with increasing costs and revenue for each combination of zones. We consider the revenue as a percentage of the leg cost. There is a chance that the truck may go back or go to the collection center generating cost and revenue. Similar to this, a truck has a probability of visiting a maintenance center, and hence generating cost and profit. The number of vehicles used is selected to show three cases: shortage in vehicles (5), about enough (90), and more than enough (110). A summary of the used parameters is given in Table I.

The results are shown in Fig. 3; from which, different conclusions can be withdrawn. First, although the total profit could be better for some of the reverse cases, but as a margin, it stays smaller than the margin for the case without reverse logistics. This is attributed to the increased fixed cost which decreases the margin percentage. In addition, this fixed cost results in a requirement for the margin out of the recycling process to be high enough to break even or even exceed the profit margin coming from the regular operation without recycling. According to the simulation, inappropriate implementation of the recycling program may lead to an overall loss despite being profitable before applying recycling. Furthermore, applying factorial analysis on the results, it was found that all the factors are significantly affecting the profit margin with little interaction between them.

TABLE I
PARAMETERS USED IN SIMULATION

Parameter	Values
Number of Zones	3,5
Number of orders per day	U(80,120)
Number of trucks	50,90,110
Revenue Percent	10%, 20%, 30%
Return Percent	5,10,15
Maintenance Cost Percent	5,10,20

VI. CONCLUSIONS AND RECOMMENDATIONS

Due to the world's colossal demand of packaging materials as well as its increasing trend, this research paper provides a proposal to convert the regular truck rental operations into a sustainable one. An effort to reduce the consumption of the raw materials is needed to make the cardboard and plastic

packaging materials as well as recycle the truck maintenance waste, which will lead to less pollution, lower rental cost, and thereby higher supply chain profitability.
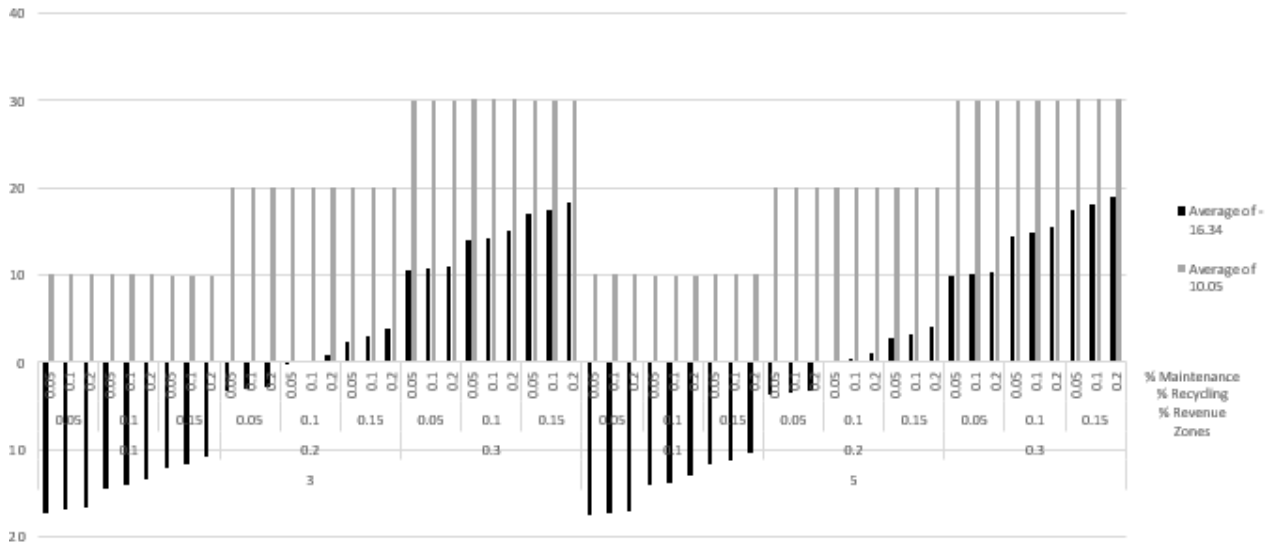

Fig. 3 Profit margin for the regular system and the proposed system with respect to different factors

The paper presents a conceptual model using the closed-loop supply chain and an optimization model to help optimization the process. The proposed optimization model identifies the appropriate locations for rental centers, collection centers, repair facilities. It also identifies the proper disposal and recycling sites. In addition, it specifies the proper rental cost that will lead to a specific profit. We also propose a simulation model to prove concept and to examine the effect of different parameters on the process. One of the important results of the research is that there should be a high profit yield of the recycling process, or impose a regulatory rule with bonuses tax credit or enforced premium cost for service without recycling.

Possible extension to this proof of concept research opens the way to possible solution algorithms including metaheuristics and exact methods.

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