REVERSE LOGISTICS NETWORK WITH DIFFERENT QUALITY LEVELS OF RETURNED COMMODITIES IN MULTI-LEVEL MULTI-COMMODITY ENVIRONMENT

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ABSTRACT: Reverse Logistics deals with the processes associated with the reverse stream from users to re-users. The returned commodities with different quality levels cannot be treated or handled in the same way because of the varying levels of problems. In order to handle such cases in the multi-commodity environment with multiple levels, we are proposing a new method. This method takes the inherent quality variations in the returned commodities into account through random variation approach. A model has been built with such additional constraint to arrive at characterization of the multi- commodity, multi-level Reverse Logistics Network. This approach provides a basis for assessing the status of the commodities and taking a decision on the repair service activities that can be made available. This treatment considers the cost structure for the repair service process as dependent logically on the status of the commodity. It is expected that the proposed approach may reduce or eliminate some of the inaccuracies involved in arriving at the characterization of the network wherein an average fixed service cost is assigned for the commodities returned. This modified approach may lead to the design and evaluation of the network, which is closer to the reality.

Keywords: Reverse logistics; Multi-commodity; Multi-level; Quality levels; Random variation approach; Service facility.

INTRODUCTION

Reverse Logistics (RL), because of its utility, it has been stretching out worldwide in various industrial sectors. RL network is an opportunity to generate additional revenue, differentiate market position, and support original product demand. Due to the variability in nature of returns, both processes and systems must maintain a degree of flexibility to manage the return process. Reverse Logistics, while making the service more responsive to customer demands, aims at the most efficient utilization of facilities, minimizing the cost of capacity. Location of facilities and the allocation of flow between facilities are important decision making areas in reverse logistics networking and its effective structuring.

Network structure is generally stated to be of great strategic importance (Christopher, 1998). When designing reverse network structures, firms need to decide where to locate the various processes and there is not usually an existing network that can be used (Fleischmann, 2001a). To determine when reverse flows should be integrated with forward flows, Fleischmann et al. (2001b) simulated the impacts of reverse flows in a logistics network. Lembke and Rogers (2001) have studied the efficiency of centralizing returns handling in the forward distribution centre itself. Fleischmann et al. (2000) reviewed several such cases and provided a thorough analysis of network design issues in the context of recovery networks. Marianov and Serra (1998) have developed several probabilistic maximals covering location-allocation models with constraints on the number of elements in the queue. Amiri (1998) included a waiting time cost in the objective function for the design of service systems.

Jayaraman et al. (2003) discussed reverse distribution, and proposed a mathematical programming model for a reverse distribution logistical problem that includes product recall, product recycling and reuse, product disposal, and hazardous product return. Ovidiu Listes (2007) presents a generic stochastic model for the design of networks comprising both supply and return channels, organized in a closed loop system and he concluded that, volume is a strong driver in the design of logistics systems with re-manufacturing options. Ovidiu Listes and Dekker (2005) presented a model for product recovery network design. Hokey Min et al. (2006) proposed a minimum-cost solution for the reverse logistics network design, involving product returns.

Maria et al. (2007) studied the design of a generic reverse logistics distribution network where capacity limits, multi-product management and uncertainty on product demands and returns are considered. Feng Du and Evans (2007) analyzed the reverse logistic networks that deal with the returns requiring repair service. Jeung Ko and Evans (2007) presented a model for the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and return network simultaneously. Lieckens and Vandaele (2007) presented an efficient design of a reverse logistics network with stochastic lead times to determine which facilities to be opened to minimize the investment, processing, transportation, disposal and penalty cost with supply, demand and capacity constraints are satisfied. Jeung and Evans (2007) designed a simultaneous network as an integrated aspect for optimizing the forward and return network**.**

In this paper, we propose a multi-level multi-commodity reverse logistics network Model, with random variation method to account for inherent variation in quality of the returned commodities. This model also considers the impact of revenue in terms of various costs. Queuing aspect is also considered in the objective function to calculate the cycle time in terms of waiting time of the commodity in the facility. Here, a "commodity" represents a specific product as stated in (Zuo-jun Max shen, (2005).

The structure of this paper is as follows. We first describe the definition of the problem and then we give the modeling of the problem. With the simulation results and finally we conclude this work.

PROBLEM DEFINITION

Customers return different types of used commodities (multi-commodity), which have become fault due to some defects during its regular working, in varying quantities at various points of time to the disposer market. The returned commodities from the disposer market (k) are immediately sent to service facilities, (j) without any intermediate storage units. The commodities after the service at the first level delivered back to the reuse market (k) or sent to the second or subsequent service facilities, if there is a need for any specialized recovery work or service.

Different types of used commodities, multi-commodities, in varying quantities and qualities arrive at a finite number of given disposer market at various points of time. When the commodity arrives into a service facility, it is inspected to identify the problem to be recovered. After the identification, it is compared with the random number (groups) ranges (figure 3 and figure 4)which were assigned by Random variation method (RVM). RVM, categorize the different problems into different groups. These different groups need different service work to be performed, each with different service cost. This step allows for an incoming commodity, to get what type of service to be performed. Then the service work carried out and the commodity sent back to the reuse customer or to the next level if the commodity needs any specialized service works. A Service cost depending on the problem was performed is claimed. This service cost is differs according to the nature of the problem of the returned commodities. Fig 1 shows this framework of multi-commodity reverse logistics network design with random variation approach.

Servicing/Reprocessing will be done on all the commodities which enter the service/repair facility with or without disposing some numbers. Here, we assume that the serviced/repaired commodities are immediately sent to the reuse market without storing. Hence, this model is limited to a single level network. Servicing generates revenue to the facility. Inventory also occurs at the facility locations. In this model we assume that the volume of supply and demand can be estimated based on technical data and with future expectations.

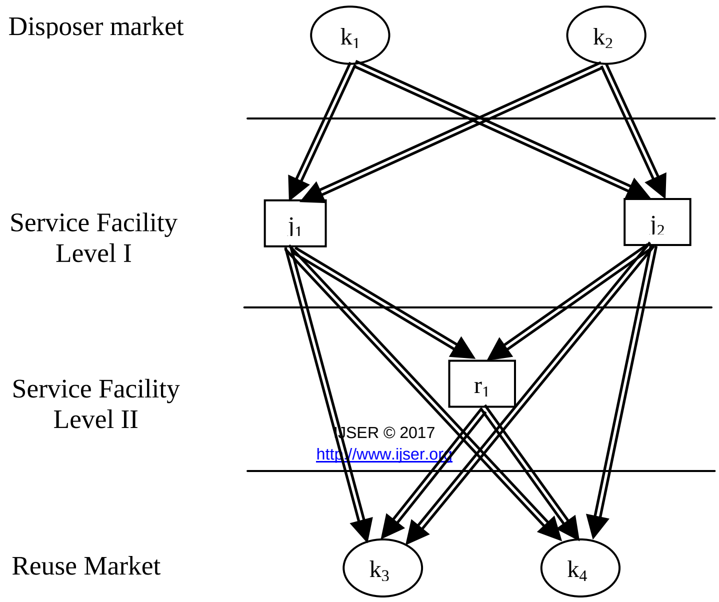

Figure 1: Structure of a multi-level multi-commodity RL network

In the current instant, as we are dealing merely with service facilities, the disposer market and the reuse market are assumed to be one and the same. The transportation of commodities between collection sites and service facilities in first level and second level is considered on individual basis i.e., the returned commodities are not collected at one place and transported to the service facilities in batches (This assumption is mere suitable for more service facilities). Periodically, the defective parts, which are to be replaced, are sent to the plants of the manufacturer for remanufacturing or for other purposes, and the replacements are transported to the service facilities from the manufacturer's plant. Figure 1 shows the structure of the multi- level, multi-commodity reverse logistics network.

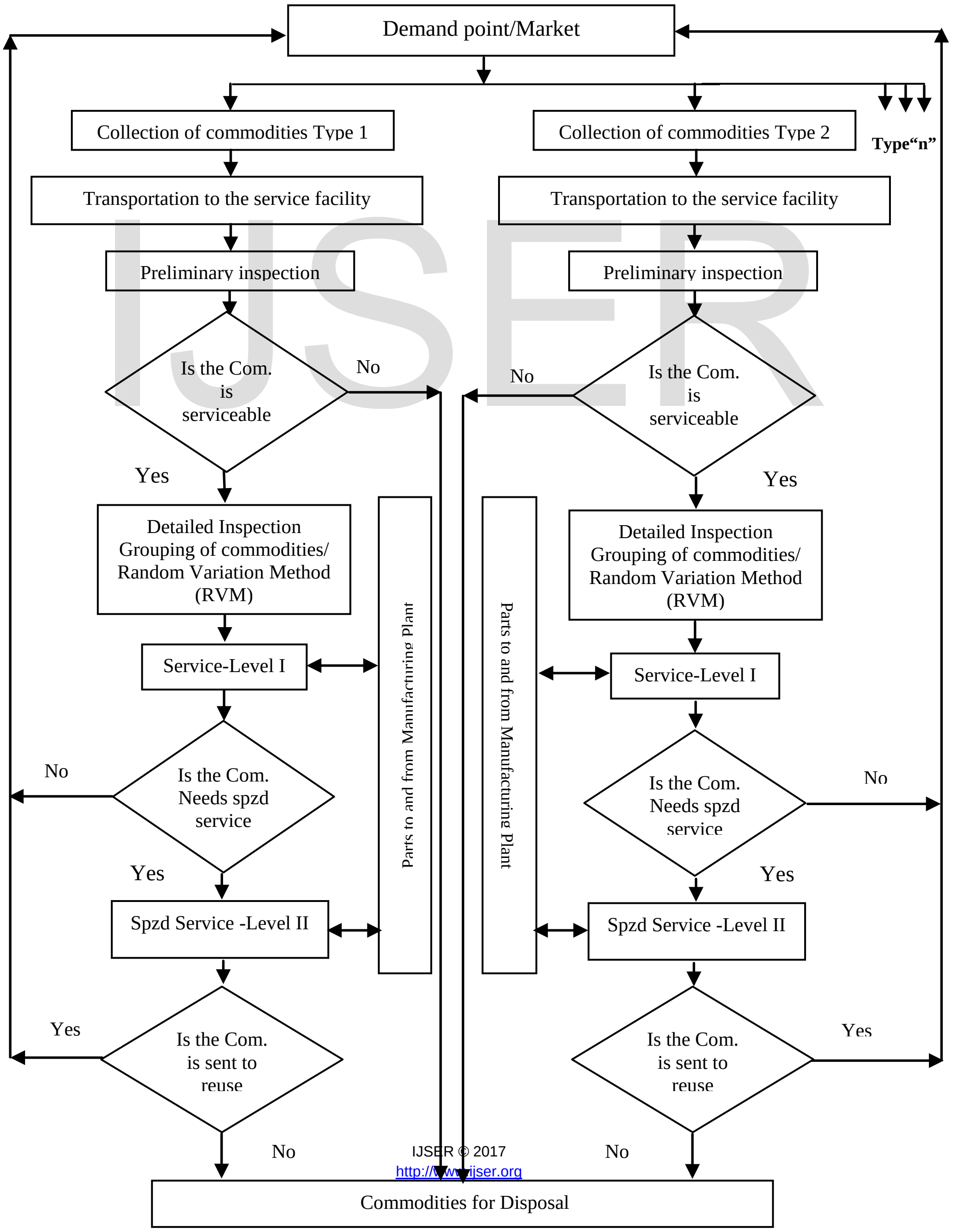

Figure 2: A frame work for multi-level multi-commodity RL Network with RVM

In this model, we assume that the volume of supply and demand and the fraction of the returns not collected are estimated based on collected technical data from the existing service facilities. The step by step flow of the commodities and service extended at various stages are clearly depicted in framework developed by the authors and shown in figure 2. The disposer market is considered as source, the repair service facilities as intermediary nodes, and the reuse market as sink.

MODELING OF A REVERSE LOGISTICS NETWORK FOR MULTI-COMMODITY FLOW

This model is a multi-commodity, multi-level reverse logistics closed loop network model with multiple service facilities with a random variation approach, constructed to have better control on the cost, revenue, and render predefined service level (Customer satisfaction). The model is designed for one-year time horizon. Binary variables are used to decide the status of the facility, while the continuous variables indicate the assigned flow of the goods. This model also takes into account the cycle time, which is found by introducing queueing relationships into the network as did by Kris Lieckens and Vandaele (2007). The main difference of this model as compared to the existing models is that it is capable of handling quality variations in the multi-level multi-commodity environment.

In this paper, we use the following notations,

INDICES

J {1. . . j, . . . , Jmax} set of repair service facility locations "j".
K {1. . . k, . . . , Kmax} set of customer locations n (both disposer and reuse markets).
Q {1. . . q, . . . , Qmax} set of capacity levels q (discrete values).
r Repair service facility at level II

DECISION VARIABLES, COSTS AND REVENUE PARAMETERS

C_{ijk} Commodity "i" flow from service facility "j", to the demand point "k".
C_{ikj} Commodity "i", flow from disposer market "k" to repair service facility "j".
C_{ijr} Commodity "i" flow from repair service facility (at level I) "j" to repair service facility at level II "r".
C_{irj} Commodity "i" flow from repair service (at level II) "r" to the demand point "k".
P_{ik} Selling price of the commodity, "i" flow from service facility "j", to the reuse market "k".
$F_{ij}(q)$ Fixed cost to open a facility "j", at capacity level "q" for the commodity "i".
$B_j(q)$ Boolean operator to indicate the status of the service facility 'j', i.e., open or not.
$R_{ij}(q)$ Unit service cost of commodity "i", flow at facility "j", operating at level "q".
$C_{ij}(q)$ Total commodity flow serviced at facility "j", at installed capacity "q".
H_{ij} Unit holding cost of commodity "i", per year at facility "j".
$E(N)_{ij}$ Expected no of commodities "i" at facility "j".
T_{ikj} Unit transportation cost between disposer market "k" and service facility "j".
D_{ik} Yearly demand of reuse customer "k" for commodity "i".
U_{ik} Fraction of demand not satisfied at reuse market, "k" for commodity "i".
PD_{ik} Unit penalty cost for not satisfying demands of reuse market "k", for commodity "i".
R_{ik} Yearly returns from disposer market "k", for commodity "i".
w_{ik} Fraction of returns not collected from disposer market "k".
PR_{ik} Unit penalty cost for not collecting the returns from disposer market "k".
C_{ij} Commodity "i", flow disposed at service facility "j".
D_{ij} Unit disposal cost at facility "k".
$M_{ij}(q)$, Maximum capacity of service facility "i", when installed at capacity level "q".

QUEUEING PARAMETERS

The returned defective commodities join the queueing system for getting serviced. Any queueing system is characterized by the following: an arrival process, a process step and a queue. Here, we are using an M/M/c with Poisson arrival and exponential service distribution and multi-server queueing model in order to find out the expected waiting time and the expected number of commodities in the service facilities.

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t_{ij}, Mean effective service time of commodity "i", at facility "j".
λ_{ij}, Arrival rate of commodity "i", to service facility "j".
μ_{ij}, Service rate of commodity "i" ,to service facility "j".
ρ_{ij}, Utilization level for commodity "i", to service facility "j".
EW_{ij}, Expected time spent by the commodity "i", at facility "j".
EN_{ij}, Expected number of commodities "i", at facility "j".

The mean effective reprocessing rate μ_{ij} at level I, which is the inverse of t_{ij} is equivalent to the maximum capacity level $M_{ij}(q)$, at which facility "j" is installed.

$$t_{ij} = \frac{1}{\mu_{ij}} = \frac{1}{\sum_q R_{ij}(q) B_{ij}(q)}$$

Similarly, the mean effective reprocessing rate μ_{ir} at level II, which is the inverse of t_{ir} is equivalent to the maximum capacity level M_{ij} (q), at which facility "r" is installed.

$$t_{ir} = \frac{1}{\mu_{ir}} = \frac{1}{\sum_q R_{ir}(q) B_{ir}(q)}$$

MODEL FORMULATION
Max Profit = Revenue – Total cost

Max

$$\sum_k^o \sum_j^m \sum_i^n C_{ijk} P_{ijk} + \sum_k^o \sum_r^s \sum_i^n C_{irk} P_{irk} - \Bigg(\sum_q^p \sum_r^s \sum_i^n F_{ij}(q) B_j(q) + \sum_q^p \sum_r^s \sum_i^n F_{ir}(q) B_r(q) +$$
$$\sum_q^p \sum_r^s \sum_i^n R_{ij}(q) C_{ij}(q) + \sum_q^p \sum_r^s \sum_i^n R_{ir}(q) C_{ir}(q) + \sum_j^m \sum_i^n H_{ij} E(N)_{ij} + \sum_r^s \sum_i^n H_{ir}(N)_{ir} + \qquad (1)$$
$$\sum_j^m \sum_k^o \sum_i^n T_{ikj} C_{ikj} + \sum_r^s \sum_j^m \sum_i^n T_{ijr} C_{ijr} + \sum_k^o \sum_i^n D_{ik} U_{ik} PD_{ik} + \sum_k^o \sum_i^n R_{ik} w_{ik} PR_{ik} + \sum_j^m \sum_i^n C_{ij} D_{ij} \Bigg)$$

CONSTRAINTS
Service facility at level I

$$R_{ik}\left(1 - w_{ik}\right) = \sum_j^m \sum_k^o \sum_i^n C_{ikj} \qquad \forall_k, \forall_i \qquad (2)$$

$$\sum_j^m \sum_k^o \sum_i^n C_{ikj} - D_{ij} = \sum_q^p \sum_j^m \sum_i^n C_{ij}(q) \qquad \forall_q, \forall_j, \forall_i \qquad (3)$$

$$\sum_q^p \sum_j^m \sum_i^n C_{ij}(q) = C_{ijk} \qquad \forall_j, \forall_k, \forall_i \qquad (4)$$

Service facility at l

$$\sum_q^p \sum_j^m \sum_i^n f\, C_{ir}(q) = \sum_r^s \sum_j^m \sum_i^n C_{ir} \qquad \forall_q, \forall_i \qquad (5)$$

$$\sum_r^s \sum_j^m \sum_i^n C_{ir} = \sum_q^p \sum_r^s \sum_i^n C_{ir}(q) \qquad \forall_q, \forall_i \qquad (6)$$

$$\sum_q^p \sum_r^s \sum_i^n C_{ir}(q) = C_{irk} \qquad \forall_k, \forall_i \qquad (7)$$

Capacity
Service facility at level I

$$C_{ij}(q) \le M_{ij}(q) \qquad \forall_i, \forall_q, \forall_j \qquad (8)$$

$$C_{ij}(q) \ge M_{ij}(q-1) \qquad \forall_i, \forall_q, \forall_j \qquad (9)$$

$$\sum_{q} B_j(q) \le 1 \qquad \forall_j \qquad (10)$$

Service facility at level II

$$C_{ir}(q) \le M_{ir}(q) \qquad \forall_i, \forall_q \qquad (11)$$

$$C_{ir}(q) \ge M_{ir}(q) \qquad \forall_i, \forall_q \qquad (12)$$

$$\sum_{q} B_r(q) \le 1 \qquad (13)$$

Logical

Service facility at level I

$$B_j(q) = [0,1] \qquad \forall_j, \forall_q \qquad (14)$$

$$C_{ij}(q) \ge 0 \qquad \forall_j, \forall_q, \forall_i \qquad (15)$$

$$C_{ikj} \ge 0; \quad C_{ijk} \ge 0; \qquad \forall_j, \forall_k, \forall_i \qquad (16)$$

$$C_{ij}(q) \ge 0 \qquad \forall_j, \forall_q, \forall_i \qquad (17)$$

Service facility at level II

$$B_r(q) = [0,1] \qquad \forall_r, \forall_q \qquad (18)$$

$$C_{ir}(q) \ge 0 \qquad \forall_r, \forall_q, \forall_i \qquad (19)$$

$$C_{ikr} \ge 0; \quad C_{irk} \ge 0; \qquad \forall_r, \forall_k, \forall_i \qquad (20)$$

$$C_{ir}(q) \ge 0 \qquad \forall_r, \forall_q, \forall_i \qquad (21)$$

Others

$$0 \le w_{ik} \ge 1 \qquad \forall_k, \forall_i \qquad (22)$$

$$0 \le u_{ik} \ge 1 \qquad \forall_k, \forall_i \qquad (23)$$

In order to facilitate the closed-loop reverse supply chain modeling, the returns points and the demand points are taken as one and the same. It literally means that in a closed-loop supply chain, those who reuse the commodities are the same as those who have disposed them. The constraints that link up the input and output streams at a facility are as follows: constraint (2) is introduced to ensure that all, or at least a part of the returned products, multi-commodities, leave the return point “k”, to a repair service facility, “j”. All the incoming flow at each facility “j” need not be serviced for various reasons. To account for the part of the serviced flow, constraint (3) is introduced. All the useful commodities at facility “j” after servicing are sent to demand point “k”, or to the next level (level II) for specialized service works, if the commodity needs and the same is considered in constraint (5). All the incoming commodities to the service level II are serviced and this is given in constraint (6). After the specialized service work, the commodities sent to demand points are taken care of by the constraint (7). Each facility is assumed to be installed at its maximum capacity, and the constraints (8) to (13) are meant for that. Constraints (14) to (24) are the logical constraints.

Commodities, which are waiting at the returns point, are the source for the queuing network. Whenever the commodities are waiting in the queue for service, for all practical purposes it can be considered that the customers who have returned them have to wait to get the commodities serviced. The commodities arrive at the service facilities with an average arrival rate of $\lambda_{ij,}$ which is equal to C_{ikj}, after accounting the fraction of returns not collected is given in equation (24). Hence, the total product flow to the repair service facility ‘j’ is C_{ikj}. Therefore, the arrival rate of the commodity ‘i’ in the queue is given by,

$$\lambda_{ij} = R_{ikj}(1 - w_{ikj}) = \sum_{j} C_{ikj} \qquad (24)$$

At the facility “j”, the average arrival rate is given in equation (25),

$$\lambda_{ij} = \sum_k C_{ikj} = \sum_j C_{ij}(q) \quad (25)$$

The expression to find out the expected yearly inventory cost at the facility ‘j’ can be formulated using Little’s law. The same is given in equation (26). Here, the relationship between the expected waiting time and the expected number of commodities in the facility has been taken into account.

$$H_{ij}[E(N)_{ij} = H_{ij}[\lambda_{ij} E(W)_{ij}] \quad (26)$$

The average expected waiting time (the cycle time) of a commodity, E (W) $_{ij}$, consists of, the average expected waiting time of the commodities in the queue E (W) $_{ij}$ and the average expected reprocessing time t_{ij}. Hence, the average expected cycle time can be given in equation (27) as**,**

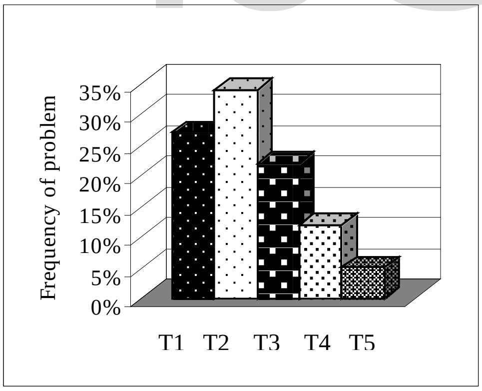
$$E(W)_{ij} = E(WQ)_{ij} + t_{ij} \quad (27)$$

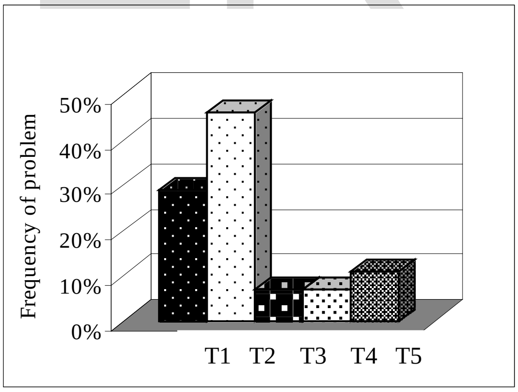
The overall expression for finding out the yearly cost of the delayed service of the facility “j”, taking into account the effective service time t_{ij} and the effective utilization level ρ_i can be given equation (28) as,

$$IC = \sum_i H_{ij}\lambda_{ij}\left[\frac{\mu_{ij}(\lambda_{ij}/\mu_{ij})^c}{(c_{ij}-1)!(c_{ij}\mu_{ij}-\lambda_{ij})^2}\right] \times \frac{1}{\sum_{n=0}^{c-1}\left[\frac{\mu_{ij}(\lambda_{ij}/\mu_{ij})^n}{n!} + \frac{\mu(\lambda_{ij}/\mu_{ij})^c}{c_{ij}!} X \frac{c_{ij}\mu_{ij}}{c_{ij}\mu_{ij}-\lambda_{ij}}\right]} + \frac{1}{R_{ij}(q)} \quad (28)$$

SIMULATION RESULTS

The multi-level, multi-commodity reverse logistics networking with queueing relationships, to incorporate commodities cycle time and different service costs developed in this work is an extension of model developed by the authors for single level multi-commodity reverse logistics network model with random variation method (Ch. Kajendirakumar and V. Soundararajan, 2007).





(T1, T2, T3, T4 and T5 are the type and extent of faults in the commodities)

Figure 3: Grouping of problem for commodity 1

Figure 4: Grouping of problem for commodity 2

The model is simulated with the real time data obtained from an existing service facility. Figures 3 and 4 show the details of the data collected. The simulation involves the number of returned commodities and the service facilities with operational costs, i.e., the fixed and using cost, service cost, transportation cost, holding cost, penalty cost and disposal costs. Tables 1 to 3 show the parameters used in this simulation. The simulation involves the number of returned commodities and the repair service facilities with the service cost towards the different types of problems in different levels. The simulation results (Table 4) shows that the flow of commodities, with random variation method to the service facilities yields maximized customer satisfaction along with profits in the reverse logistic network with multiple levels.

Table 1: Flow of multi-commodities in the RL network

Supply (k)	Facility, Level I (j)	Commodity (1)	Commodity (2)			Facility (j)	Market (k)	Commodity (2)	Commodity (1)
C_{ikj}	1	1	C_{111}	C_{211}	C_{ijk}	*1*	*3*	C_{113}	C_{213}
	1	2	C_{112}	C_{212}		*1*	*4*	C_{114}	C_{214}
	2	*1*	C_{121}	C_{221}		*2*	*3*	C_{123}	C_{223}
	2	*2*	C_{122}	C_{222}		*2*	*4*	C_{124}	C_{224}
	Level I	Level II			*Facility(r)*				
C_{ijr}	1	3	C_{113}	C_{213}	C_{irj}	3	3	C_{133}	C_{233}
	2	3	C_{123}	C_{223}		3	4	C_{134}	C_{234}

Table 2: Different cost involved in the simulation for service facilities at Level 1

Facility (j_1)	FC	SP	SC	HC	TC	PDC	U	PRC	w	DC
Commodity 1	125000	3000	2400	50	100	75	0.02	50	0.0	100
Commodity 2	125000	2625	2100	50	100	75	0.02	50	0.0	100
Facility (j_2)										
Commodity 1	150000	2500	3125	50	125	50	0.02	75	0.0	100
Commodity 2	150000	2200	2750	50	125	50	0.02	75	0.0	100

Table 3: Different cost involved in the simulation for service facility at Level II

Facility (r)	FC	SP	SC	HC	TC	PDC	U	PRC	w	DC
Commodity 1	300000	2550	1275	50	125	50	0.02	75	0.0	100
Commodity 2		2250	1125	50	125	50	0.02	75	0.0	100

Table 4: Computational results

Variables			Setting 1		Setting 2		Setting 3	
			Commodity1	Commodity2	Commodity1	Commodity2	Commodity1	Commodity2
C_{ikj} Supply (k) → facility (j) to level I`								
	1	1	852	180	810	170	700	160
	1	2	740	129	782	132	892	142
	2	1	828	178	805	165	795	145
	2	2	773	142	800	155	800	175
Supply C_{iji} Facility level I → level II								
	1	1	226	44	226	43	227	43
	2	1	228	45	229	46	227	46
C_{ijk} Facility (j)- level lI → Demand (k)								
	1	1	809	174	769	161	665	152
	1	2	703	123	743	125	847	135
	2	1	787	169	765	157	755	138
	2	2	734	135	760	147	760	166
C_{ijk} Facility (j)-level II → Demand (k)								
	1	1	226	44	226	43	227	43
	1	2	228	45	229	46	227	46
$X_i(q)$ Facility (i)-level I → Capacity (q)								
	1	2	500	250	500	250	500	250
	2	2	500	250	500	250	500	250
$X_i(q)$ Facility (i)-level II → Capacity (q)								
	1	2	250	100	250	100	250	100
C_{ikj} Satisfied demand (k) from level I								
	1		1512	297	1512	286	1512	287
	2		1521	304	1526	304	1515	304

from level II							
	1	454	89	455	89	454	89
$E(N)_{ij}$ Expected no of commodities (No) Facility(j)⟶ level I							
	1	5	1	4	1	3	1
	2	3	1	4	1	6	1
Facility (j)⟶ level II							
		1	1	1	1	10	1
$E(W)_{ij}$ Expected waiting time (minutes) Facility(j) ⟶ level I							
	1	8.33	8.88	6.22	7.35	5.16	8.41
	2	5.69	7.95	8.23	8.27	10.19	8.12
Facility (j) ⟶ level II							
	1	0.022	0.012	0.026	0.012	0.023	0.012
Profit in INR		4049097.25		3807865.12		3643428.30	

CONCLUSIONS

Reverse logistics networks are always tied with their inherent uncertainties. In this work, we formulated a closed loop model, which adequately takes care of the repair service activities in multiple levels with consideration for different quality level of returned commodities. The formulation has been done with the objectives of having better cost control and maintenance of reasonable or acceptable service level from the customers' angle. The result shows that channelizing of commodities to the existing service facilities based on the Random variation approach may results in maximized profit.

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