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Surendra M. Gupta
Northeastern University

Kishore K. Pochampally
Northeastern University

Sagar V. Kamarthi
Northeastern University

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Contact Information

Dr. Surendra M. Gupta, P.E.
Professor of Mechanical and Industrial Engineering and
Director of Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA 02115, U.S.A.

(617)-373-4846 ***Phone***
(617)-373-2921 ***Fax***
gupta@neu.edu ***e-mail address***

http://www.coe.neu.edu/~smgupta/ ***Home Page***

IDENTIFICATION OF POTENTIAL RECOVERY FACILITIES FOR STRATEGIC PLANNING OF AN EFFICIENT REVERSE DISTRIBUTION NETWORK

Kishore K. Pochampally, Northeastern University, Boston, MA 02115, (617)-216-2508, pocham@coe.neu.edu
Surendra M. Gupta*, Northeastern University, Boston, MA 02115, (617)-373-4846, gupta@neu.edu
Sagar V. Kamarthi, Northeastern University, Boston, MA 02115, (617)-373-3070, sagar@coe.neu.edu
(*Corresponding author)

ABSTRACT

Strategic planning of a distribution network is one of the most challenging aspects of reverse logistics. To effectively satisfy drivers such as profitability, environmental regulations and asset recovery, only the recovery facilities that have the potential to efficiently reprocess used-products must be considered in the reverse distribution network design. Due to uncertainties in supply, quality and reprocessing times of used-products, traditional forward logistics approaches to identify potential manufacturing facilities are not appropriate for direct adoption in reverse logistics. This paper proposes a mathematical programming approach, taking the above uncertainties into account, to effectively select potential facilities from a set of candidate recovery facilities. Application of the approach is detailed through an illustrative example.

BACKGROUND

Reverse logistics is the movement of used-products from consumers towards producers within a distribution network. Possible drivers for companies interested in used-products are recoverable value through reprocessing (remanufacturing/recycling), environmental regulations, product stewardship and asset protection [4].

Any reverse distribution network consists of at least three parties: collection centers where consumers return used-products, recovery facilities where reprocessing is performed and demand centers where customers buy reprocessed goods *viz.*, output of recovery facilities. Figure 1 illustrates the flow of goods from collection centers to demand centers through recovery facilities in a generic reverse distribution network.

While there are many strategic, tactical and operational aspects that are considered in designing and operating a reverse distribution network, this paper concentrates on strategic planning that ideally should involve (i) identification of potential recovery facilities and (ii) transportation of right mix and quantities of products (used as well as reprocessed) across the network. While many location models can be found in the literature (see [2] for a good review) that deal with the transportation issue, no paper addresses the problem of identification of potential recovery facilities in designing a reverse distribution network. In the case of discrete location models (for example, [6]), all the recovery facilities are assumed to be potential and in the case of continuous location models (for example, [5]), it is assumed that potential recovery facilities were already established or can be established at the locations solved for. Evidently, though the location models, especially the discrete ones, realize the importance of considering only those facilities that have enough potential to reprocess used-products, they do not show how to identify those potential facilities. This paper proposes a mathematical programming approach to identify potential recovery facilities based on internal relationship between decision variables of the candidate recovery facilities.

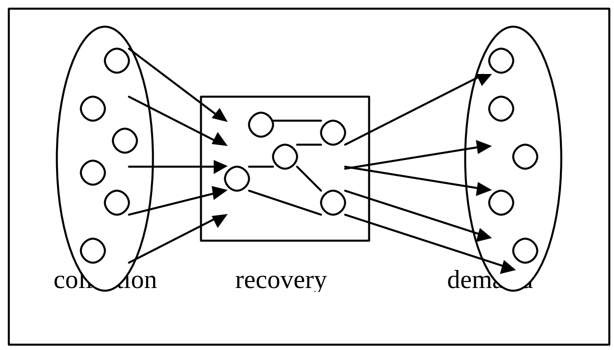

Figure 1.Generic reverse distribution network

PROBLEM AND SOLUTION STRATEGY

Although identification of potential manufacturing facilities has been addressed in forward logistics (flow of goods from suppliers to consumers through manufacturers; see for example, [1], [8], [9]), those approaches are not suitable for direct adoption in reverse logistics. This is due to the problems associated with reprocessing, which include: (1) uncertainties in supply and timing of used-products, (2) unknown quality and quantity of components in used-products and (3) stochastic reprocessing times of used-products. To tackle these problems, we take certain additional factors into account in our approach. These factors are introduced and described in the next section.

A data envelopment analysis model, referred to as CCR (Charnes-Cooper-Rhodes) model [3] from hereon, is applied in forward logistics to identify potential suppliers and potential manufacturers [8], [9]. Essentially, the model maximizes the efficiency of a target facility (supplier or manufacturer) k, from among a reference set of facilities s, by selecting the optimal weights associated with input and output measures. The efficiency formulation is expressed as follows:

$$\text{Maximize } E_{kk} = \frac{\sum_y O_{ky} v_{ky}}{\sum_x I_{kx} u_{kx}}$$

subject to

$$E_{ks} = \frac{\sum_y O_{sy} v_{ky}}{\sum_x I_{sx} u_{kx}} \leq 1 \qquad \forall \text{ facilities } s,$$

$$u_{kx}\ ,\ v_{ky}\ \geq\ 0,$$

where O_{ky} is the amount of output y produced by facility k, I_{kx} is the amount of input x used by facility k, u_{kx} is the weight assigned to input x by facility k, v_{ky} is the weight assigned to output y by facility k, O_{sy} is the amount of output y produced by facility s and I_{sx} is the amount of input x used by facility s. E_{ks} is also called cross-efficiency of facility s with respect to optimal CCR weights of facility k. Cross-efficiencies give information about how well a facility is performing with respect to optimal CCR weights of other facilities.

A potential weakness of applying the CCR model is that it may suggest a high optimal efficiency value by indulging in an inappropriate and unrealistic weighting structure. To avoid making an unfair decision, a cross-efficiency matrix is sometimes utilized [7]. The cross-efficiency matrix is formed by aggregating the entire information about cross-efficiencies into rows and columns. An element in the ith row and jth column of the matrix denotes the cross-efficiency of facility j when using optimal CCR weights of target facility i. The decision maker considers a facility good if it achieves a high column mean. The CCR model together with the cross-efficiency matrix reduce the complexity of the problem by minimizing the number of facilities that are to be used for further analysis and increase the efficiency of the solution by considering only the potential facilities in the location model. In a later section, we present an illustrative example for the application of the CCR model with the corresponding cross-efficiency matrix to identify potential facilities from a set of candidate recovery facilities.

I/O MEASURES IN REVERSE LOGISTICS

Though it is vague in the literature as to what measures should to be taken as outputs and what measures should be taken as inputs in the CCR model, we believe that it is reasonable to take measures of benefits to the facility as outputs and all the corresponding measures of costs to the facility as inputs in the reverse logistics case. For example, for a recovery facility, the number of reprocessed products produced per unit time measures a benefit to the facility and so we take 'average throughput' as an output. The average throughput depends upon the number of employees in the facility, which in turn measures a cost to the facility, and so we take 'number of employees' as an input.

Though the outputs (for example, average throughput, inverse of average work-in-process, average quality level of reprocessed products, utilization ratio and number of reprocessed product options) are similar in reverse logistics to those in forward logistics, there are three special inputs that need to be added in reverse logistics to the list of regular inputs (for example, number of employees, number of machines and fixed cost of the facility per period). The following is a brief description of each of those additional inputs:

Average disassembly time of incoming goods

Average disassembly time is not exactly the inverse of average throughput because throughput takes into account the whole reprocessing (disassembly plus recovery) time. Unlike in forward logistics, components of incoming goods (*i.e.*, used-products) in a recovery facility are likely to be deformed and/or broken and/or different in number even for the same type of goods. Hence, incoming goods for the same type might have different reprocessing times, unlike in forward logistics where manufacturing time and assembly time are pre-determined and equal for goods of the same type. Since average throughput of a recovery facility depends upon the average disassembly time of the incoming goods, it is unfair to judge a facility using the CCR model without considering the average disassembly time as an input.

Complement of average quality of incoming goods

Unlike in forward logistics, components of incoming goods of even the same type in a recovery facility are likely to be of varied quality (worn-out, low- performing, etc). Since average quality of reprocessed goods depends upon the average quality of incoming goods, it is unfair to judge a recovery facility using the CCR model without considering the average quality of incoming goods. A notable point here is that since we would like to take only the measures of costs to the facility as inputs in the CCR model, the average quality of incoming goods is complemented and then taken as an input. For example, if the average quality of the incoming goods is represented by a percent, say 60%, the complement of it *i.e.*, 40% gives a measure of the cost involved in improving the goods' average quality. This is clearer when one thinks more in terms of a remanufacturing facility.

Supply of incoming goods

The only driver to design a forward distribution network is the demand for new products and so if there is low demand for new products, there is practically no forward distribution. However, this is not the case in some reverse distribution networks where even if there is low supply of used-products, reverse logistics must be administered due to the possible drivers like environmental regulations and asset recovery. In supply-driven cases like these, it is unfair to judge a recovery facility without considering the supply of incoming goods as an input.

ILLUSTRATIVE EXAMPLE

The following example illustrates the application of the CCR model with cross-evaluations for identification of potential recovery facilities. In this example, seven candidate recovery facilities (R's) are considered for analysis. The following is the list (not exhaustive) of I/O measures considered for each recovery facility in this example:

Inputs: Average disassembly time in seconds (DT), Average fixed cost per period in thousands of dollars (plant cost, equipment cost, etc) (FC), Number of employees working in the facility (NE), Complement of average quality level of used-products as a percentage (CQI) and Average supply of used-products per period (SU)

Outputs: Product options (number of types of product that can be reprocessed) (PO), Average throughput per minute (TP) and Average quality level of reprocessed products as a percentage (QO)

We used Lingo (version 4) to implement the CCR model. Of the seven recovery facilities considered, the CCR model identified recovery facilities 1, 3, 4, 5 and 6 to be with an optimal efficiency score of 1. These results are shown in Table 1.

Table 1. I/O measures and optimal efficiencies

R	Inputs					Outputs			Max E_{kk}
	FC	DT	CQI	NE	SU	PO	TP	QO	
1	90	20	0.55	37	50	6	0.067	0.99	1.00
2	120	20	0.65	55	90	4	0.056	0.95	0.96
3	110	25	0.70	35	99	2	0.045	0.99	1.00
4	95	90	0.43	35	79	8	0.050	0.97	1.00
5	110	80	0.35	50	90	7	0.040	0.96	1.00
6	70	85	0.67	43	100	4	0.042	0.93	1.00
7	84	85	0.51	52	90	2	0.033	0.92	0.98

We then utilized cross-efficiencies and aggregated them into a matrix to calculate their means. This matrix is shown in Table 2. Of the seven recovery facilities, recovery facilities 5, 6, and 7 have mean cross-efficiencies values of less than 70 percent. If the cutoff limit decided by the decision maker is 70 percent, he will identify 1, 2, 3, and 4 as potential recovery facilities.

Table 2. Cross-efficiencies

R	1	2	3	4	5	6	7
1	1.00	0.85	0.57	0.17	0.16	0.16	0.13
2	1.00	0.96	0.80	0.22	0.24	0.22	0.22
3	1.00	0.67	1.00	1.00	0.75	0.77	0.68
4	0.78	0.55	0.51	1.00	1.00	0.54	0.57
5	0.62	0.46	0.40	0.86	1.00	0.44	0.52
6	0.99	0.68	0.89	0.96	0.75	1.00	0.81
7	0.98	0.74	0.79	0.98	0.92	0.99	0.98
Mean	0.91	0.70	0.71	0.74	0.69	0.59	0.56

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