Performance Analysis of Storage Warehouses in a Food Grain Supply Chain using Data Envelopment Analysis

Akash Karande, Ajay Krishna, Jayasurya R, Gokul Gopan, M Vishnu Gopinath,
Sachin Kumar, Anoop K.P, Vinay V Panicker[#] and G. Varaprasad
Department of Mechanical Engineering,
National Institute of Technology Calicut; Calicut, India.
[#]Author for correspondence; vinay@nitc.ac.in;

***Abstract* -Food Grain Procurement Organization takes the responsibility of storing food grains in the country for Public Distribution System and other welfare programmes. Operating warehouses is a challenging task due to the various reasons such as seasonality in the procurement of grains, deviation from the movement plan, delays in the lifting operation of food grains from warehouses and in-flexible nature of work-force. Through this study, a Data Envelopment Analysis (DEA) model is developed to calculate the relative efficiency of warehouses owned by an Indian Food grain procurement organisation. The model is used to establish ranking among warehouses.**

Keywords-Data Envelopment Analysis; Food grain supply chain; Charnes Cooper Rhodes; Super efficiency;

I. INTRODUCTION

The need for food grains is seeing a rapid increment mainly due to the increase in the global population. To fulfil this burgeoning demand, there is a requirement for an increase in production, procurement and less wastage of food grains during transit and storage. The food grain procurement organization is accountable for maintaining the procured goods, their storage and distribution activities throughout the country. This particular job considers the aspect of movement and storage of the food grains undertaken by a food grain procurement organisation in the Southern part of India. Currently, 45% of the food grain particles right from the end of the harvest to the stage of distribution are being wasted because of improper handling, movement, infrastructure and facilities. [1].

Transport of food grain particles is essential to replenish buffer stock in deficient areas and also to meet requirements. On an average in a year, 40 to 42 million tonnes of food grains are transported within the country on a monthly basis. Food grain transport is done with the help of Road, Rail, and Waterways, in which Indian Railway accounts for about 85% of stock transportation [1]. Road transportation are done in those areas where rail transportation is not possible.

The warehouses face difficulties in their operation due to the unsteady flow of the grains, delays in the lifting operation of the grains and the inflexibility of the work-force. The warehouses fail to use their storages to the maximum extent. Therefore, the storage utilization has a great influence on the output of the warehouse and this causes inefficiency.

The day and time of arrival of the food grains in the warehouse also has a critical effect on the efficiency. In this context, when the food grain procurement organization take more time in release of a rake than the allotted time, a Demurrage cost is to be paid to the Railways as penalty. The detention hour is the extra time the trains stay at the station. As the detention hours' increase, the demurrage cost increases and the warehouse efficiency decreases. Proper planning should be done for resolving the problem of detention hours. In addition, there is a need for an effective utilization storage facility and work-force.

Rest of the paper is organized in the following manner: Relevant literature reviews are presented in Section 2. Section 3 describes solution approach and the model formulation adopted through this study. Section 4 provides results and discussion. The paper concludes in section 5.

II. REVIEW OF LITERATURE

Warehouse management system is a necessary approach for improvement of every warehouse. An automated warehousing system provides less effort, more efficient, and reliable results compared to manual handled system [2]. DEA is a parametric linear programming technique that measures relative efficiencies. Same set of parameters are chosen for all the DMUs and they are grouped into input and output parameters according to their nature. These parameters are given as input into the DEA model so as to find the relative efficiency of each DMU [3].

Selection of Warehouse operator by the combination of Analytic Hierarchy Process and DEA, provide a systematic and flexible criterion for selection [4]. It consists of preliminary analysis that involves stating the objectives for

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network design problem, finding the best possible location, alternative warehouse operators, gathering and analysing information.

Machine learning procedure was incorporated with DEA for assessing the efficiency of system integration ventures. The focal point of this work was to conquer the confinements of DEA through hybrid investigation using DEA alongside machine learning by creating guidelines to group DMUs into various levels [5]. Two tale strategies to be specific performance benchmarks and perform correspondence benchmarks were utilized to assess the proficiency of DMUs utilizing Singular Value Decomposition procedures in DEA setting [6].

Fuzzy Data Envelopment Analysis (FDEA) is used when there is uncertainty in the data values. In such scenarios, the various outputs and inputs of DMU's are taken as non-symmetric triangular shaped fuzzy numbers [7]. FDEA method is formulated using the CCR model by incorporating the non-symmetric triangular shaped fuzzy inputs and outputs data using α-cut method. DEA was combined with goal programming to set benchmarks and rank sustainable suppliers for their efficiency improvement. This method was found to be efficient for both efficient and inefficient DMUs [8]. This helped the managers to shift the focus from supervision to future planning. This model also helped to recognize future inefficiencies and make preventive decisions.

In the Indian food security system the study of warehouse efficiency improvement by comparing two cases with and without Radio Frequency Identification (RFID) Technology for managing the inventory was conducted [9]. It considered spoilage and misplacement of stocks as a cause of stock incorrectness and definition of the complete expected expense in instances of with and without RFID was performed and their legitimacy in the Indian Targeted Public Distribution System (TPDS) was looked at.

III. SOLUTION APPROACH AND MODEL FORMATION

Charnes, Cooper, and Rhodes (1978) proposed the idea of Data Envelopment Analysis (DEA) and following this the very first DEA model was named CCR (Charnes, Cooper and Rhodes) model. DEA is a non-parametric scientific procedure utilized for evaluating the overall effectiveness of DMUs in a generation framework which can have different data sources and various yields without any suspicions of assuming production functions or the systems utilized for production [3]. This non-parametric model is non-direct which is changed over to a Linear Programming (LP) definition and understood with help of numerical modelling software and weights for each DMU is assigned. The weights for each linear aggregation allotted are the consequences after comparing LP. The weights are picked in order to demonstrate the particular DMU in a positive light as conceivable that is the maximum efficiency gotten is the most extreme feasible for the DMU.

Let n decision making units DMU_j (j = 1, . . . , n) be assumed which has the purpose of converting m inputs x_{ij} (i = 1, . . . , m) into s outputs y_{rj} (r = 1, . v. . , s) and let DMU_o be the DMU being evaluated. Suppose the output and input weights are numbers that are non-negative. The efficiency value of DMU_o which is θ_0 under the assumption is to estimated such that the of all DMUs have efficiency values less than or equal to unity. Ratio of the Weighted sum of outputs to the the weighted sum of inputs is named as the efficiency of DMUs. So, weights v_i (i = 1 , . . . , m) and u_r (r = 1, . . . , s) are given to inputs and outputs, separately and the equations which follow are used to determine the effectiveness values of these DMUs:

Objective function

$$Max\theta_0 = \frac{u_1y_{1o} + u_2y_{2o} + \cdots + u_sy_{so}}{v_1x_{1o} + v_2x_{2o} + \cdots + v_mx_m}$$

Subject to constraints

$$\frac{(u_1y_{1j} + u_2y_{2j} + \cdots + u_sy_{sj})}{(v_1x_{1j} + v_2x_{2j} + \cdots + v_mx_{mj})} \leq 1 \ (j = 1,2 \ldots n)$$
$$v_1, v_2 \ \ldots, v_m \geq 0$$
$$u_1, u_2 \ldots, u_s \geq 0$$

To solve this model the above non-linear equations are converted to linear equations assuming the sum of weighted inputs of that specific DMU equal to unity.

Objective function

$$Max\theta_0 = u_1y_{1o} + u_2y_{2o} + \cdots + u_sy_{so}$$

Subject to constraints

$$v_1x_{1o} + v_2x_{2o} + \cdots + v_mx_m = 1$$
$$(u_1y_{1j} + u_2y_{2j} + \cdots + u_sy_{sj}) - (v_1x_{1j} + v_2x_{2j} + \cdots + v_mx_{mj}) \leq 0$$
$$v_1, v_2 \ \ldots, v_m \geq 0$$
$$u_1, u_2 \ldots, u_s \geq 0$$

On the off chance that a DMU is observed to be inefficient, a blend of other effective DMUs can be utilized as benchmark for that DMU and create either more prominent output for a similar aggregate of inputs or utilize less contributions to deliver a similar composite of outputs or a blend of the two in order to build the effectiveness of that DMU.

Many times for evaluating the efficiency of the DMUs using simple CCR based DEA more than one DMU give efficiency score of unity, which creates problem while ranking the DMUs. So to get different values for efficiencies the constraint in DEA which states that the efficiency of that specific DMU is less than or equal to unity is removed which helps in enabling an extremely efficient DMU to obtain an efficiency score that is more than one but this time the value of efficiencies is different for all DMUs and now they can be easily ranked. This model is called Super efficiency model [10]. The study has been conducted among sixteen warehouses operated by the Food Grain Procurement Organization. Table I represents the input and output parameters of warehouses for DEA formulation

TABLE I. Input and output parameters for DEA formulation

INPUT PARAMETERS	OUTPUT PARAMETERS
Storage capacity (SC)	Monthly labour utilisation (ML)
No of workers (W)	Monthly capacity utilisation (MC)
Number of wagons placed (NoWP)	
DC hours in the month (DC)	

TABLE II. Data set for one problem instance

Warehouse	Input				Output	
	SC	*W*	*No WP*	*DC*	*ML*	*MC*
A	10000	40	221	27	0.897	0.551
B	40000	91	158	29	0.147	0.717
C	10000	39	84	46	0.344	1.007
D	15320	58	154	68	0.374	0.435
E	30000	38	79	24	0.335	0.173
F	36136	72	191	63	0.280	0.647
G	11900	37	232	146	1.176	0.583
H	5000	44	145	61	0.570	0.905
I	48960	74	84	7	0.128	0.602
J	20000	58	117	58	0.316	0.349
K	10640	99	84	64	0.076	0.602
L	9500	53	84	33	0.252	0.441
M	70740	83	113	30	0.186	0.629
N	29000	70	74	3	0.185	0.690
O	45000	78	63	23	0.112	0.393
P	35160	105	295	80	0.166	0.466

Data regarding different parameters of warehouses are collected from various secondary sources. Data such as warehouse capacity, capacity utilization and work force for each warehouse has been collected. The formulated DEA model is coded in AMPL and solved as a Linear Programming problem using CPLEX solver.

IV. RESULTS AND DISCUSSIONS

This section discusses the results obtained from the AMPL solver. The final output from those models will be the relative efficiencies of each DMU and the corresponding weights for input and output parameters. The results of CCR and Super efficiency model solved in AMPL are shown in the Table III along with the corresponding ranking based on super efficiency model. It is found that some DMUs (Warehouses) namely A, C, G, H and N have relative efficiency of 1. These are the efficient DMUs. To differentiate between the efficiencies of efficient DMUs, the Super efficiency model is used and the result is displayed in the Table III. The final results of ranking of all the warehouses for twelve such instances are tabulated in Table IV.

Table III Results of CCR and Super efficiency model in AMPL for the given instance.

Warehouse	CCR	Super Efficiency	Rank
A	1.000	3.040	1
B	0.577	0.573	11
C	1.000	1.717	4
D	0.544	0.544	14
E	0.959	0.959	6
F	0.428	0.428	15
G	1.000	1.417	5
H	1.000	2.125	3
I	0.768	0.768	7
J	0.589	0.589	10
K	0.598	0.598	9
L	0.719	0.719	8
M	0.529	0.529	13
N	1.000	3.007	2
O	0.565	0.565	12
P	0.224	0.224	16

Table IV Results of ranking of warehouses based on Super efficiency model in AMPL for 12 instances.

	Ranks of warehouses for twelve different problem instances											
DMU	1	2	3	4	5	6	7	8	9	10	11	12
A	9	1	3	2	2	2	6	3	3	2	2	6
B	8	11	9	15	10	11	11	11	9	10	9	15
C	6	4	4	4	1	3	3	4	6	9	8	1
D	13	14	11	9	12	10	1	14	15	14	13	14
E	10	6	7	6	4	6	7	6	2	3	1	2
F	16	15	5	10	8	4	10	12	11	6	3	7
G	7	5	6	5	5	5	5	5	5	7	6	3
H	2	3	1	3	3	8	2	2	4	1	4	4
I	1	7	8	11	11	12	12	9	12	5	12	10
J	4	10	13	12	13	15	15	13	10	11	7	11
K	11	9	12	8	7	9	9	7	1	15	11	8
L	12	8	10	7	6	7	8	10	7	8	10	12
M	3	13	14	14	15	14	14	15	13	13	15	13
N	5	2	2	1	9	1	4	1	8	4	5	5
O	15	12	15	13	14	13	13	8	14	12	14	9
P	14	16	16	16	16	16	16	16	16	16	16	16

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From the above table, the performance of each warehouses over a time period of twelve problem instances is determined. Each problem instance is considered having a time period of one month. Figure 1 shows the trend line for each warehouses.

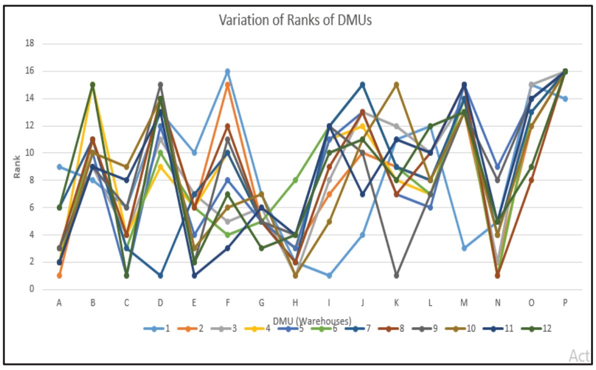

Fig.1. Variation of ranks of DMUs for each instance.

From the above Figure, it is found that the warehouses A, E and H shows a highly efficient performance, consistently throughout the time period while, warehouse P performs with least efficiency throughout.

V. CONCLUSIONS

The operation of warehouses is considered to be a challenging task in any supply chain. Considering a food grain supply chain, the operation becomes more difficult due to the various reasons like seasonality in the procurement of grains, deviation from the movement plan, delays in the lifting operation of food grains from warehouses and in-flexible nature of work-force. This work is done in a food grain procurement organisation in the Southern part of India.

In this work, a Data Envelopment Analysis (DEA) model is developed to evaluate the relative efficiency of warehouses and establish ranks among them. Based on the application of Data Envelopment Analysis, the following insights are drawn about the performance of warehouses involved in a Food Grain Supply Chain.

- Development of CCR model among sixteen warehouses provided an efficiency of unity among five warehouses and therefore to differentiate a Super efficiency model is developed to rank the efficient DMUs.

- Data collected has been normalised and solved for the model for both CCR and Super Efficiency which yielded the same result signifying that the method adopted is accurate.

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