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Development of a Reverse Logistics Performance Measurement System for a battery manufacturer

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Abstract

In this contribution, the case of a leading Lead Acid Battery manufacturer in India is studied with respect to the essential reverse logistics operations of the company, due to the statutory requirements regarding toxic components in the product. The critical parameters are ascertained by a methodology interviews with the company's management and further consolidated using the taxonomy as suggested by the Balanced Scorecard approach. Then, a performance measurement system vis-à-vis the industry benchmark, over a sustained period, is proposed, using Fuzzy Analytical Hierarchical Process.

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Keywords: Reverse Logistics; Performance Measurement; Balanced Score Card; Fuzzy AHP; Lead Acid Battery

1. Introduction

Reverse logistics deals with the recovery of products, systems, devices, material from the market by the seller of these products. Recovery of products encompasses the chain of buy back, transporting, warehousing and recycling. The origin of the term itself is difficult to trace as stated by De Brito(2002). It appears in the form of terms like Reverse Channels or Reverse Flow in the scientific literature of the seventies, but more in the scope of recycling (Guiltinan and Nwokoye, 1974; Ginter and Starling, 1978). Due to the rise in environmental awareness driven legal incumbencies, world over, in the late nineteen nineties and the increased acceptance of potential economic benefits of recovery operations (Guide and Wassenhove, 2001), the importance of reverse logistics as an important operation for producers themselves has grown. The Lead Battery Management and Handling Act, 2001 lays down rules for all members of the supply chain.

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However, for the manufacturer, it makes it legally binding in the schedule to recover 50% in the first year after legislation i.e. 2002, 70% in the second year and 90% in the third year onwards where all percentages are in the form of portions of new batteries sold. This is a challenging figure to achieve, given the very protean nature of the quantity recovered from the costumer. The establishment of germane factors that together subsume all the various facets of this operation is key. For this, this paper proposes an approach based on the Balanced Scorecard, put forth by Dr. Robert S. Kaplan and Dr. David P. Norton, widely used for forward (conventional) supply chains (Bhagwat and Sharma, 2007). In the following sections we aim to use the criterions so obtained to build a Performance Measurement (PM) solution for the producer using fuzzy AHP, on the lines proposed by Mohammed Shaik and Walid Abdul-Kader (2012) who used simple AHP techniques, but by exploring techniques suggested by Da Yong Chang et al (1996) to convert the ratings to triangular fuzzy numbers, and in-turn, performance scores.

2. Literature Review

Over the past few years, new outlooks towards the supply chain structures have been developing (Seuring and Muller,2008). The increased focus on environmental preservation has substantiated the need for integrating reverse logistics activities with forward supply chains. Reverse logistics is concerned with the management of equipments, products, components or technical systems being recovered (Marisa P de Brito and Rommert Dekker,2002).Thierry et al.(1995)outlines recovery options ranging from re-use to land filling and incorporating them within the supply chain. Carter and Ellram (1998) presented a model involving the drivers and constraints related to reverse logistics .Goggin and Browne(2000) proposed a classification for end-of-life recovery of products focusing on electronic and electrical equipments. The Reverse Logistics objective of retrieving returned products ,while harnessing the economic value within them, poses a daunting task (Ferrer& Whybark,2000,Guide& van Wassenhove,2003).Hence, a comprehensive performance measurement system needs to be developed to realize RL objectives. Various Performance Measurement frameworks have been stated in literature (Sharma et al.,2005).Reverse Logistics Performance Measurement frameworks however incorporate different criteria than those employed in Forward Supply Chain ,as RL chains are affected by different driving forces. Autry et al,.(2001) observed that sales volume affects the performance of reverse logistics significantly. Richey et al.,(2005) found that resource allocation towards the development of advanced capabilities for handling of returns can improve the RL performance. Ravi et al.(2005) provided a model to address the RL problem of computers while Yellepeddi et al.(2005) proposed a performance index for reverse supply chain in electronics industry using the BSC approach and ANP method. Mohammed Shaik et al.(2012)developed a comprehensive performance measurement system for reverse logistics of an enterprise using BSC approach and applying AHP to prioritize the performance criteria. This paper introduces a case study on the design of a performance measurement system for the reverse logistics of a leading battery manufacturing company, using the BSC approach and fuzzy AHP.

3. Research Methodology

3.1 Balanced Score Card

With the aim of developing a performance measurement system for the reverse logistics of the lead acid battery manufacturer, this investigation follows the approach of a balance scorecard as developed by Kaplan and Norton. The main objective behind the BSC is to form a limited set of indicators that form an interpretive framework of the reverse logistics chain, to give top management a quick and comprehensive overview of the system. The following four perspectives are considered:

Table 1: The four perspectives in a balanced scorecard (Kaplan and Norton, 1992)

Perspective	Mission
Financial (shareholder's view)	To succeed financially and deliver value to shareholders
Stakeholder(value addition view)	To achieve our vision by delivering value to the customer
Process	To promote efficiency and effectiveness of the business process
Learning and growth(future view)	To achieve our vision, by sustaining innovation and changecapabilities, and preparing for future challenges

3.2 Fuzzy AHP

Value of fuzzy synthetic extant :
Let X = {X1, X2,…,Xn} be an object set and U = {U1, U2,…, Um} be a goal set. Using Chang's extent analysis each object is taken and extent analysis for each goal is performed, respectively (Chang, 1996). Therefore, M-extent analysis values for each object can be obtained as shown follows:

$$M_{g_i}^{1}, M_{g_i}^{2}, ..., M_{g_i}^{m}, \qquad i = 1,2,....,n \tag{2}$$

Where all the $M_{g_i}^{j}$ *(j=1,2,....n)* are triangular fuzzy numbers (TFNs) whose parameters are *l, m, u*. *l* represents the least possible value ,*m*represents most possible value and *u* represents largest possible value.
synthetic fuzzy extent value for i^{th}object is :

$$s_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \tag{3}$$

$\sum_{j=1}^{m} M_{g_i}^{j}$ can be obtained from the matrix by adding the M extant analysis values such that

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left[\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right] \tag{4}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} = \left[\sum_{i=1}^{n} \sum_{j=1}^{m} l_{ji}, \sum_{i=1}^{n} \sum_{j=1}^{m} m_{ji}, \sum_{i=1}^{n} \sum_{j=1}^{m} u_{ji} \right] \tag{5}$$

and inverse of equation (5) will be :

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} u_{ji}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} m_{ji}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} l_{ji}} \right] \tag{6}$$

Degree of possibility:
The degree of possibility of M_1being greater than M_2 can be defined as:

$$V(M_1 \geq M_2) = \sup_{x>y} (\min\{\mu_{M1}(x), \mu_{M2}(y)\}) \tag{7}$$

The above equation is equivalent to the following set of equations

$$V(M_1 > M_2) = 1 \qquad iff\ m_1 \geq m_2$$

$$V(M_1 \leq M_2) = hgt(M_1 \bigcap \qquad l)$$

$$= \begin{pmatrix} 0 & if\ l1>u2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{pmatrix} \tag{8}$$

Where *d* is the ordinate of highest point of intersection D between μ_{M_1} *and* μ_{M_2} (As in Figure 1).

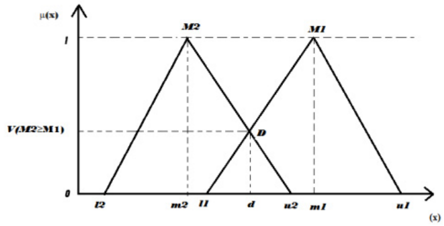

Fig 1. Triangular fuzzy numbers ***M1*** *and* ***M2***

The degree of possibility for fuzzy number M to be greater than convex fuzzy number M_i (i=1,2,..,n) can be defined as:

$$V(M \geq M_1, M_2, ..., M_n) = V[(M \geq M_1) \; and \; (M \geq M_2) \; and......and \; (M \geq M_k)] \\ = min \; V(M \geq M_i), \qquad i = 1,2,......,k. \qquad \textbf{(9)}$$

Assume that

$$d'(A_i) = \min \; V(S_i \geq S_k), \qquad k = 1,2,.....,n; i \neq k \qquad \textbf{(10)}$$

Then, the weight vector is given by

$$W' = \{d'(A_1), d'(A_2), ..., d'(A_n)\}^T \qquad \textbf{(11)}$$

where A_i (i =1,2,....,n) are *n* elements. The normalized matrix W can be written as:

$$W = \{d(A_1), d(A_2), ..., d(A_n)\}^T \qquad \textbf{(12)}$$

Here W is a non-fuzzy number. In this research, we have used the triangular fuzzy conversion scale proposed by Chang (1996) to convert linguistic judgment into fuzzy triangular numbers (as shown in table 2).

Table 2: Triangular fuzzy conversion scale (Chang,1996)

Linguistic scale	Triangular fuzzy conversation scale	Triangular fuzzy reciprocal scale
Just Equal	(1, 1,1)	(1,1, 1)
Equally Important	(2/3, 1, 3/2)	(2/3, 1,3/2)
Weakly More Important	(1, 3/2, 2)	(1/2, 2/3,1)
Moderately More Important	(3/2, 2, 5/2)	(2/5, 1/2,2/3)
Strongly More Important	(2, 5/2, 3)	(1/3, 2/5,1/2)
Extremely More Important	(5/2, 3, 7/2)	(2/7, 1/3,2/5)

4. CASE STUDY

4.1 Company profile

Company ABC is the second largest inverter and UPS battery company in India; providing fresh, viable and lasting alternative to battery industry starved by long monopoly of one brand.It has an installation base of more than 5 million batteries and a nationwide network of more than 1700 dealers and 1800 distributors, 38 branch offices and 210 customer care centers and 10 plants all across India.

4.2 Identification of factors

The first and a very important step to fabricate the performance measurement framework was to identify the factors on which the performance of the Reverse Logistics system depends. We got the opportunity to visit the company and have an interactive discussion with some of the senior members of the firm. After studying the process of battery recycling and the related data provided by the company in detail, we identified various factors which affect the performance of the system and hence should be monitored in the PM framework.The relative importance of each of these factors toward the goal was specified by the company and we chose top 9 factors (out of 13) to form the basis of performance measurement in our framework. BSC was used and these 9 factors were identified under its four main perspectives.

Financial Perspectives

1. Return on Investment: Setting up a big battery recycling plant with all the high technology machines is a capital intensive process. Every firm aims at achieving high return on investment.
2. Profit: Profit reflects how much the operations are earning, in absolute terms. Needed apart from ROI.

Customer Perspective

1. Buyer Supplier Relationship: In case of reverse cycle, the distributor is the supplier and the company purchasing the scrap battery is the buyer. It is very important to monitor the relation between them as only a healthy relation of the company with the distributor will help them retrieve scrap battery from them. They are given incentives so that the suppliers prefer them over other buyers in market.
2. Fuel Consumption: Saving on fuel is a means to increased profitability and safeguarding the environment.

Internal Business Perspective

1. Cycle Time:Cycle time of each machine, the bottleneck process affects the cycle time of the complete process and reducing the cycle time enhance the productivity. Thus it is also a contributing factor for PM system
2. Machine Availability: Not only high tech machines but there availability is equally important i.e. the probability that the machine is available for use at required time. Maximum capacity utilization yields higher productivity and in turn improves the performance of the system. Thus machine availability is an important factor in determining the performance of the system.
3. Recovery: The amount of lead recovered as a percentage of the input lead is both a factor with environmental as well as monetary significance.

Innovation and Growth

1. Quality of documentation: It is very important to retain all the important and relevant data in a proper organized and easily accessible format so that it can be easily retrieved without any time wastage.
2. Effectiveness of collection planning schedule: The efficiency with which the scrap batteries are collected from the doorstep of the consumer and delivered to the company is important for the recycling process.

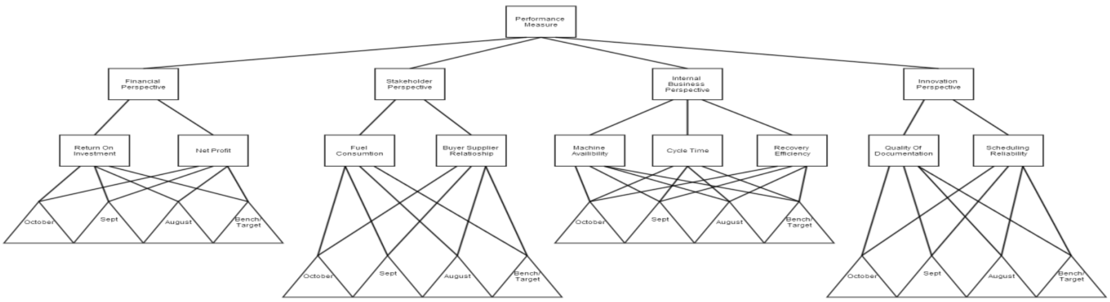

Fig 2. AHP Consolidated Factors Tree Diagram

4.4 Data related to identified factors

Table 3.Quantitative data

	OCT	SEP	AUG	BENCHMARK
No of batteries retrieved	15937	8544	6270	42857
Profit (Rs) (extrapolated to per year)	2860691.5	1533648	1125465	7692831.5
ROI	6.01%	5.42%	5.03%	6.53%
Machine Availability	63.6%	62.5%	65%	95%
Recovery Efficiency	0.92	0.93	0.85	0.95
Total fuel consumption (mixed unit)	452.7	414.1	452.34	285
Cycle time (days)	16	18	15	15

4.4.1 Contribution of criteria in performance measurement

The linguistic judgement of the experts is quantified into a fuzzy pairwise matrix with the help of the Chang's triangular fuzzy number conversion scale, in order to capture the inherent uncertainty and ambiguity present in human judgement.

Table 4. Fuzzy pair wise comparison of performance drivers

	Profit	ROI	CT	RE	M/C Av.	B-S	Coll.	Fuel	Doc
Profit	(1,1,1)	(0.4,0.50,0.67)	(2,2.5,3)	(1,1.5,2)	(1.5,2,2.5)	(1.5,2,2.5)	(2,2.5,3)	(1.5,2,2.5)	(1.5,2,2.5)
ROI	(1.5,2,2.5)	(1,1,1)	(2,2.5,3)	(1.5,2,2.5)	(1.5,2,2.5)	(1.5,2,2.5)	(2,2.5,3)	(1.5,2,2.5)	(1.5,2,2.5)
CT	(0.33,0.4,0.67)	(0.33,0.4,0.67)	(1,1,1)	(0.5,0.67,1)	(1.5,2,2.5)	(1,1.5,2)	(1.5,2,2.5)	(1,1.5,2)	(1.5,2,2.5)
RE	(0.5,0.67,1)	(0.4,0.5,0.67)	(0.5,0.67,1)	(1,1,1)	(0.67,1,1.5)	(1.5,2,2.5)	(2,2.5,3)	(1.5,2,2.5)	(1.5,2,2.5)
M/C	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.67,1,1.5)	(1,1,1)	(1.5,2,2.5)	(2,2.5,3)	(1.5,2,2.5)	(1,1.5,2)
B-S	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.5,0.67,1)	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(1,1,1)	(1,1.5,2)	(0.5,1,1.5)	(0.67,1,1.5)
Coll.	(0.33,0.4,0.5)	(0.33,0.4,0.5)	(0.4,0.5,0.67)	(0.33,0.4,0.5)	(0.33,0.4,0.5)	(0.5,0.67,1)	(1,1,1)	(0.5,1,1.5)	(0.67,1,1.5)
Fuel	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.5,0.67,1)	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.5,0.67,1)	(0.5,0.67,1)	(1,1,1)	(1,1.5,2)
Doc	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.4,0.5,0.67)	(0.5,0.67,1)	(0.67,1,1.5)	(0.67,1,1.5)	(0.5,0.67,1)	(1,1,1)

The vector thus obtained is normalized to give the final normalized weights of each criterion as given in the table 5. Thus we have calculated the contribution of each criteria to the performance goal and now proceed to rate each alternative with respect to each other under the 9 criteria.

4.4.2 Inter alternative performance measurement

Now we do as before for each individual criteria separately. The matrices are processed in a similar fashion as stated earlier, to find the respective weights of each alternative under that particular criterion. Quantitative criterions are converted based on their ratios. The fuzzy pairwise matrices and their weights are shown below:

Table 5. Fuel Consumption

	October	September	August	Benchmark	Weights
October	(1,1,1)	(2/3,1,3/2)	(1,3/2,2)	(2/5,1/2,2/3)	0.22
September	(2/3,1,3/2)	(1,1,1)	(1,3/2,2)	(2/5,1/2,2/3)	0.22
August	(1/2,2/3,1)	(1/2,2/3,1)	(1,1,1)	(2/5,1/2,2/3)	0.04
Benchmark	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.52

Table 6. Cycle Time

	October	September	August	Benchmark	Weights
October	(1,1,1)	(1,3/2,2)	(2/3,1,3/2)	(2/3,1,3/2)	0.28
September	(1/2,2/3,1)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0.08
August	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.32
Benchmark	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.32

Table 7. M/C Availability

	October	September	August	Benchmark	Weights
October	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	0.09
September	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	0.09
August	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	0.17
Benchmark	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.64

Table 8. ROI

	October	September	August	Benchmark	Weights
October	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1/2,2/3,1)	0.39
September	(2/5,1/2,2/3)	(1,1,1)	(1,3/2,2)	(2/5,1/2,2/3)	0.14
August	(2/5,1/2,2/3)	(1/2,2/3,1)	(1,1,1)	(2/5,1/2,2/3)	0.02
Benchmark	(1,3/2,2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.45

Table 9.Profit

	October	September	August	Benchmark	Weights
October	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(2/5,1/2,2/3)	0.28
September	(1/2,2/3,1)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	0.10
August	(1/2,2/3,1)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	0.10
Benchmark	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.52

Table 10. Recovery Efficiency

	October	September	August	Benchmark	Weights
October	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(1/2,2/3,1)	0.27
September	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(1/2,2/3,1)	0.27
August	(2/5,1/2,2/3)	(2/5,1/2,3/2)	(1,1,1)	(2/5,1/2,2/3)	0.10
Benchmark	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)	(1,1,1)	0.36

Table 11.Quality of Documentation

	October	September	August	Benchmark	Weights
October	(1,1,1)	(1/2,2/3,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	0.10
September	(1,3/2,2)	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	0.17
August	(2/3,1,3/2)	(1,3/2,2)	(1,1,1)	(2/5,1/2,2/3)	0.22
Benchmark	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.51

Table 12. Effectiveness of Collection Schedule

	October	September	August	Benchmark	Weights
October	(1,1,1)	(1/2,2/3,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	0.11
September	(1,3/2,2)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	0.22
August	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	0.16

Benchmark	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.51

Table 13. Buyer Supplier Partnership Level

	October	September	August	Benchmark	Weights
October	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(2/5,1/2,2/3)	0.28
September	(1/2,2/3,1)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2/,2/3)	0.06
August	(1/2,2/3,1)	(2/3,1,3/2)	(1,1,1)	(1/3,2/5,1/2)	0.03
Benchmark	(3/2,2,5/2)	(3/2,2,5/2)	(2,5/2,3)	(1,1,1)	0.63

4.4.3 Final Performance Evaluation

To obtain final performance for each month, the weight of that particular month under each criteria is multiplied by the weight assigned to that criteria, all these numbers are added up to give resultant weight of that month.
Similar procedure is followed for the benchmark. Toobtain the performance index of each month, the resultant weight of that month is divided by the resultant weight of the benchmark.

Table 14. Monthly Performance of Reverse Logistics System

	Criteria Wieghts	*October Rating*	*October Score*	*September Rating*	*September Score*	*August Rating*	*August Score*	*Benchmark Rating*	
Return On Investment	*0.1986641*	*0.39*	*0.0766740*	*0.14*	*0.0286421*	*0.02*	*0.0032104*	*0.45*	*0.09013*
Recovery Efficiency	*0.298447*	*0.27*	*0.0806304*	*0.27*	*0.0806304*	*0.10*	*0.0308696*	*0.36*	*0.10631*
Cycle Time	*0.144707*	*0.28*	*0.0411039*	*0.08*	*0.0111752*	*0.32*	*0.0462140*	*0.32*	*0.04621*
Profit	*0.166542*	*0.27*	*0.0454368*	*0.12*	*0.0203216*	*0.12*	*0.0203216*	*0.48*	*0.08046*
Machine Availibility	*0.143084*	*0.09*	*0.0135822*	*0.09*	*0.0135822*	*0.17*	*0.0237377*	*0.64*	*0.09218*
Buyer-Supplier Coordination	*0.016577*	*0.26*	*0.0042768*	*0.00*	*0*	*0.00*	*0*	*0.74*	*0.0123*
Collection Schedule	*0.024021*	*0.11*	*0.0025304*	*0.22*	*0.0052905*	*0.16*	*0.0039053*	*0.51*	*0.01229*
Fuel Consumption	*0.004006*	*0.22*	*0.0008866*	*0.22*	*0.0008866*	*0.04*	*0.0001406*	*0.52*	*0.00209*
Quality Of Documentation	*0.003948*	*0.10*	*0.0004008*	*0.17*	*0.0006529*	*0.22*	*0.0008625*	*0.51*	*0.0020*
Total	*1*	*1.994079*	*0.265522*	*1.315445*	*0.1611818*	*1.1429912*	*0.1292619*	*4.5474839*	*0.44403*

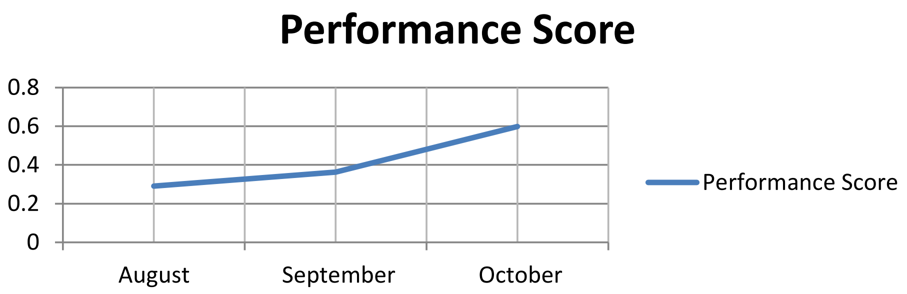

Figure 3. Month-wise performance of RL

5. Conclusion

The method proposed by this paper creates a robust performance measurement system inclusive of both qualitative and quantitative parameters. The model proposed on the basis of 9 parameters has been made such that it can accentuate the performance scores output on the basis of the past performance. The created system was used to measure the performance of a leading battery manufacturer across three months. The plot of the performance score of the company with respect to time was plotted. A comprehensive framework has been proposed with a unique way to incorporate both qualitative data and quantitative data into one comprehensive performance score. This is crucial as many aspects are often intangible but very important to consider. The system as a whole is key to give a truthful and concise picture to the manager.

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