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DELIVERY PERFORMANCE MEASUREMENT IN AN INTEGRATED SUPPLY CHAIN MANAGEMENT: CASE STUDY IN BATTERIES MANUFACTURING FIRM

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Abstract

Delivery performance provides an indication of how successful the supply chain is at providing products and services to the customer. This metric is most important in supply chain management as it integrates the measurement of performance right from supplier end to the customer end. Present research is focused on a case study conducted in a leading batteries manufacturing firm in South India and analysis of elemental performances in overall delivery performance of an entire supply chain in an integrated approach. NLP and Dynamic Programming models have been used to get optimal and sub-optimal solutions to help firms in benchmarking expected performance levels. The effect of learning has also been described with an empirical analysis.

Keywords: Supply Chain, Delivery Performance, Benchmarking and learnability index.

1. INTRODUCTION

Delivery performance can be defined as the level up to which products and services supplied by an organization meet the customer expectation. It provides an indication of the potentiality of the supply chain in providing products and services to the customer. This metric is most important in supply chain management as it integrates (involves) the measurement of performance right from supplier end to the customer end.

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After critical review of several research articles on supply chain performance measurement, it has been identified that the focus was mostly on a few one dimensional key performance indicators. In most of the cases, the models developed were more specific in nature with a goal of optimizing the objective function (constrained or unconstrained) of limited scope in a particular setup. The focus was narrow to make profit / improvement in performance for a single organization or particular industry under consideration as a case. The limitations of these models will not lend them to be used in any kind of industry setup or any supply chain in a generic sense to make profits to all firms along the supply chain. Also, industry specific models may not be affordable to other types of industries due to inherent deficiencies (due to model assumptions / limitations) in the formulation of such models. In several cases, the research scope was limited in improving performance in terms of decreasing cost, reducing cycle time / lead time, increasing profits, eliminating wastages, etc., may be helpful for any firm along a supply chain, provided there is knowledge sharing and integrated approach in problem solving among the firms.

Now, the need arose to identify and implement cross-industry performance measurement tools that would provide solution to inter-organizational transactions. There are three important flows in any supply chain. Material flow down stream, cash flow upstream and information flow in both the directions. In the present paper, an integrated approach to measure delivery performance from material flow aspect considering elemental performances of trading partners along the supply chain of a batteries manufacturing firm.

2. REVIEW OF RELEVANT LITERATURE

Today's manufacturing industry is characterized by strong interdependencies between companies operating in globally distributed production networks. The operation of such value-added chains has been enabled by recent developments in ICTs and computer networking. To gain competitive advantages and efficiency improvements such as reduced inventory and higher delivery reliability, companies are introducing information exchange systems that communicate demand to suppliers and production progress information to customers in the network (Rupp & Ristic, 2004).

Hiroshi Katayama & David Bennett (1999) examined the relationship between agility, adaptability and leanness in terms of their overall purpose and characteristics. Performance measures such as set up time, operational cycle time, variety of products that can be offered, procurement lead time, on-time delivery to customers, delivery lead time and speed of new product development have been analyzed under four process categories: operational processes, supply processes, order fulfillment processes and product development processes. Agility and adaptability have been investigated by analyzing survey data on strategy and performance, collected from major Japanese companies.

J. Liu et al., (2005) developed a common integrated management system (Workflow supported inner Supply Chain Management system) for Nanjing Jin Cheng Motor Cycle Corporation Limited and most of its suppliers to manage their inner processes. It was built on an MS SQL server, www server and browser. The results of implementation of WSCM system were: rapid response to ever changing market, stability and operability of the manufacturing plan, very low inventory levels, 15% reduction in average life cycle of products in warehouse, quick flow of information along supply chain and improved working capital management.

Garg et al., (2004) argued that the supply chain process is complex, comprising a hierarchy of different levels of value-delivering business processes. Achieving superior delivery performance is the primary objective of any industry supply chain. As the number of resources, operations and organizations in supply chain increases, variability destroys synchronization among the individual processes, leading to poor delivery performance.

In an integrated supply chain, coordination of logistical activities is effectively extended to encompass source, make and deliver processes in collaboration with channel partners and suppliers. Intra-firm coordination of sourcing, production and logistics activities enhances the ability to respond to market volatility by eliminating redundant activities and reducing response time by facilitating seamless flow of demand information, supply of materials and finished goods (Bowersox et al., 1999; Mahamani and Rao, 2010).

Dinesh Garg et al. (2003) presented a novel approach to achieve variability reduction, synchronization and hence improved delivery performance in supply chain networks using Variance Pool Allocation problem to a linear Make-To-Order (MTO) supply chain with 'n' stages. Also, the research in the field of logistics provided technology-driven solution to the distribution systems in terms of high delivery reliability, customer satisfaction and quick response.

Reward system to recognize team work and cooperation in logistics interdepartmental relations (Ellinger, 2000), Efficient Consumer Response (Alvarado & Kotzab, 2001), safety stock cost effect of reverse logistics (Minner, 2001), supplier performance measurement in logistics context from OEM's perspective (Schmitz & Platts, 2004), Integrating transportation with supply chain process (Mason & Lalwani, 2004), 4PL: Fourth Party Logistics Providers for seamless logistic solution to the client for quick response (Liston et al., 2007) are a few contributions on the role of logistics in an integrated supply chain management.

There are several performance sub-measures connected to delivery e.g: on- time delivery (Katayama & Bennett, 1999; Li & O'Brein, 1999; Garg et al., 2004), delivery reliability (Garg et al. 2003; Rupp & Ristic, 2004; Michael & McCathie, 2005), faster delivery times (Bowersox et al., 1999; Liu et al., 2005), delivery service, delivery frequencies (Katayama & Bennett, 1999), delivery synchronization (Lee & Whang, 2001) , delivery speed (Mason et al., 2003), Order fulfillment lead time (Tannock et al., 2007), Supplier's delivery performance (Morgan & Dewhurst, 2008) etc. Organizations must decide which of these sub-measures are most appropriate to measure, such as delivery from suppliers, delivery within their own organization or delivery to customers. On-time delivery (OTD) is therefore a major concern of the manufacturing as well as the distribution functions.

3. METHODOLOGY

The present work is a step towards measuring delivery performance of an integrated supply chain considering procurement, manufacturing, logistics and distribution functions.

In level-2 of SCOR model, delivery performance has four elements.

a) Supplier on-time and in full delivery

b) Manufacturing schedule attainment

c) Warehouse on-time and in full shipment

d) Transportation provider on-time delivery

The working definitions of the above elements are as follows:

1. Supplier on-time and in full delivery: It is the ratio of the number of purchase orders fulfilled by supplier(s) on-time (with flaw less match of quality, quantity and price as quoted in purchase order and invoice) to the total number of purchase orders placed per period.

$$\text{Supplier on}-\text{time and in full delivery} = \\ = \frac{\text{No.of purchase orders fulfilled on time \& in full}}{\text{Total No.of purchase orders placed per period}} \quad (1)$$

2. Manufacturing Schedule attainment: It is the fraction of manufacturing schedules attained as per production plan on-time and in full per period.

$$\text{Manufacturing Schedule attainment} = \\ = \frac{\text{No.of mfg. schedules attained on time \& in full}}{\text{Total No.of mfg. schedules placed per period}} \quad (2)$$

3. Warehouse on-time and in full shipment: It is the ratio of number of consignments dispatched to ware house (B-2-B) or directly to the customer (B-2-C) as per customer commit date to the total number of customer orders per period.

$$\text{Warehouse on}-\text{time and in full shipment} = \\ = \frac{\text{No.of customer orders delivered on time \& in full}}{\text{Total No.of customer orders placed per period}} \quad (3)$$

4. Transportation provider on time delivery: It is the ratio of number of times transportation provider (3PL) placed trucks on-time to the total number of times transportation facility is requested per period.

$$\text{Transportation provider on}-\text{time delivery} = \\ = \frac{\text{No.of times trucks placed on time}}{\text{Total No.of times facility requested per period}} \quad (4)$$

It can be observed that the four elements discussed above assume a value between 0 and 1. Now let us declare these variables as follows:

Let Ps - Fraction of on-time and in full delivery of raw materials by supplier(s) per period;

Pm - Fraction of manufacturing schedules attained as per production plans per period;

Pw - Fraction of on-time and in full shipment of goods to warehouse(s) / directly to customer(s) per period and

Pt - Fraction of on-time placement of trucks and delivery of goods by transportation provider(s) per period.

The overall delivery performance may be taken as the product of the above four factors treating each of them as probability of success in a sequence of stages.

Delivery performance:

$$(Pd) = Ps \cdot Pm \cdot Pw \cdot Pt \quad (5)$$

2.1. Formulation of the Model

Problem: To formulate a model to measure delivery performance of a supply chain and benchmark for improvement.

Model Assumptions:

(I) The success / failure of any aspect i.e., supplier(s) on-time delivery, manufacturing schedules' attainment, on-time shipment to warehouse(s) / customer(s) and transportation providers' on-time placement of trucks and delivery of goods, is independent of the others.

(II) The terms Ps, Pm, Pw and Pt represents the performance levels of all potential suppliers, manufacturing units and transportation providers.

i.e., $Ps = \prod_{i=1}^{n} Psi$ for 'n' potential suppliers.

Similarly Pm, Pw, Pt may be estimated for given no. of manufacturing units, warehouses / customer segments and transportation providers.

Our objective is to maximize the delivery performance (Pd). Since the objective function as per equation (5) is non linear, a NLP model is used that would provide an optimal solution to the problem.

$$\text{Maximize } Pd = Ps \cdot Pm \cdot Pw \cdot Pt$$

Subject to

$$Ps \leq 1,$$
$$Pm \leq 1,$$
$$Pw \leq 1,$$
$$Pt \leq 1,$$
$$Ps, Pm, Pw, Pt \geq 0.$$

The above problem is solved using 'LINGO'.

The formulation and solution of the

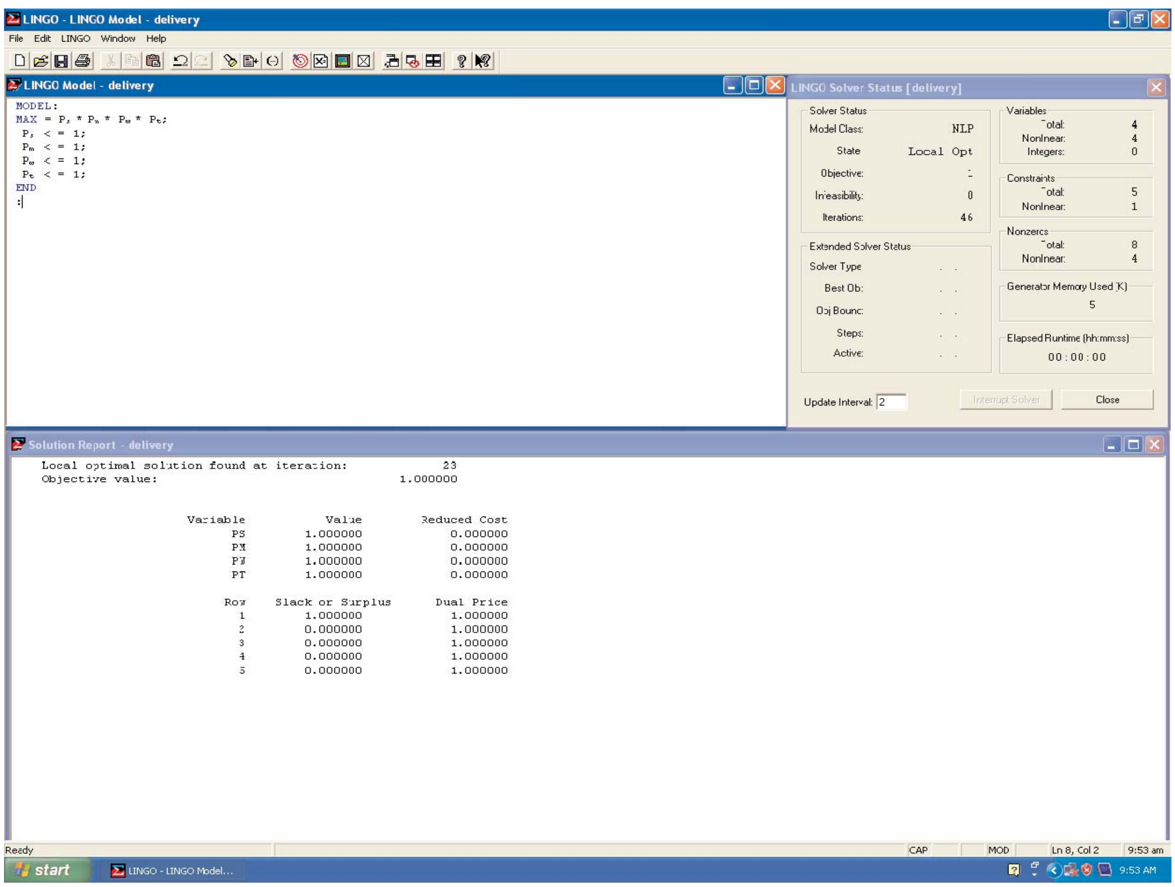

Figure 1. LINGO model formulation for Non Linear Programming problem and solution to Delivery Performance

problem in LINGO is presented in Figure 1. The optimal solution obtained after few iterations is as follows:

Maximum value of Pd = 1 where Ps = Pm = Pw = Pt = 1

This means that the optimum delivery performance is 100% with each of the factors at 100% performance level.

In reality, when supply chain philosophy has been adapted by a group of firms after mutual agreements on terms and conditions of strategic partnership, initially, the performance may not be much promising as per expectations. Also the investment on supply chain management will be significant but with little or no result. As the supply chain matures, the costs are controlled, performance levels will be improved. In such case, first of all we have to look at the current performance level and corresponding costs so that the status of the firm(s) will be understood. Passing through successive sub-optimal stages in steps by benchmarking, the firm(s) along the supply chain can improve their performances for the benefit of all. In this regard, we need sub-optimal values for bench marking. One of the most promising algorithms that provide sub-optimal solutions in a multi-stage optimization is Dynamic Programming approach. Dynamic programming is useful in making a sequence of interrelated decisions by systematically identifying optimal combination of decision alternatives under varying conditions. The above problem is a four-stage optimization problem. The recursive relations are very simple and the solution proceeds by

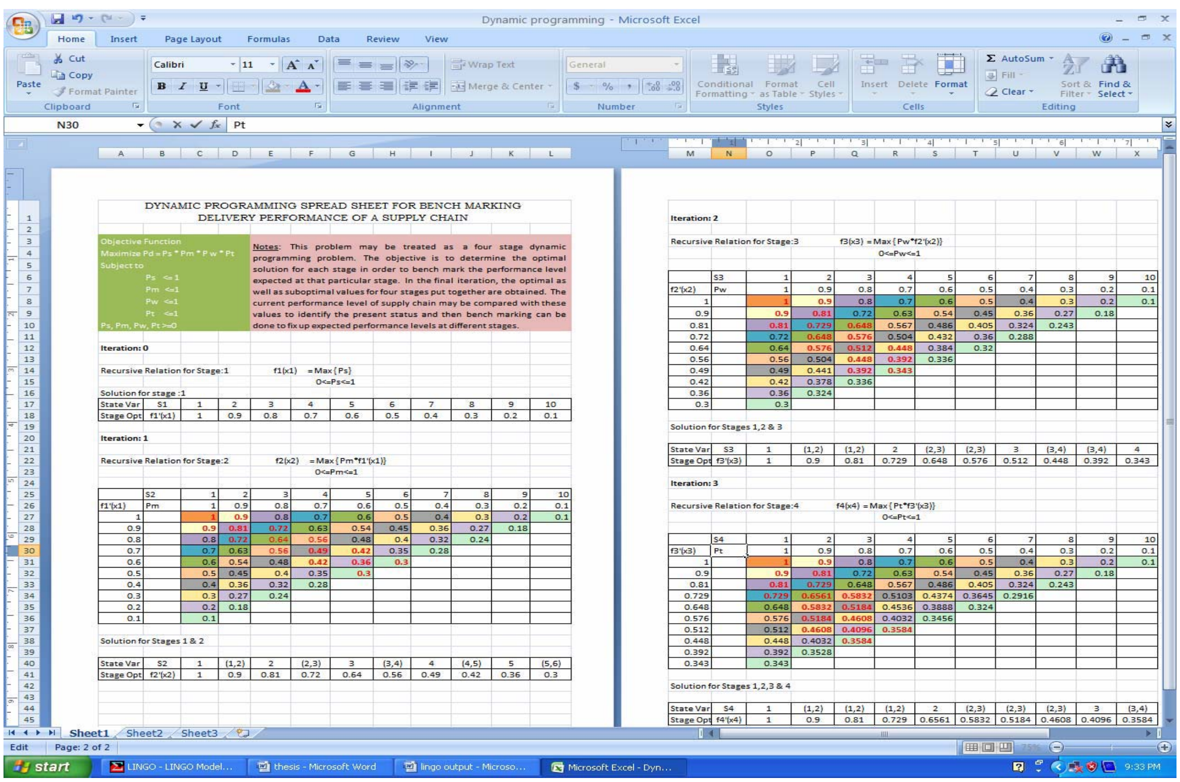

Figure 2. Spread Sheet showing iterations of Dynamic Programming approach for benchmarking delivery performance

identifying optimal values of the state variable at each stage. For simplicity, the values of each of the factors are taken in steps of 0.1 in the data range of 0 to 1.

Let Si = State variable at stage 'i'
fi (xi) = stage variable
fi ' (xi) = stage optimal

Recursive relations:
For stage: 1

$$f1'(x1) = \max_{0 \le Ps \le 1} \{Ps\} \quad (6)$$

For Stage: 2

$$f2'(x2) = \max_{0 \le Pm \le 1} \{Pm*f1'(x1)\} \quad (7)$$

For Stage: 3

$$f3'(x3) = \max_{0 \le Pw \le 1} \{Pw * f2'(x2)\} \quad (8)$$

For Stage: 4

$$f4'(x4) = \max_{0 \le Pt \le 1} \{Pt * f3'(x3)\} \quad (9)$$

The calculations are carried out in Microsoft Office EXCEL spread sheet for the four iterations (fig: 2). In first iteration, the suppliers' on-time and in full delivery is alone considered. In second iteration, fractions representing suppliers' on-time and in full delivery are multiplied by fractions representing manufacturing schedule attainment. In third iteration, the fractions representing the optimal combination for stages 1 & 2 put together are multiplied by

Table 1. Stage optima for delivery performance

Iteration:1											
State Variable	S_1	1	2	3	4	5	6	7	8	9	10
Stage Optima	$f_1'(x_1)$	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Iteration:2											
State Variable	S_2	1	(1,2)	2	(2,3)	3	(3,4)	4	(4,5)	5	(5,6)
Stage Optima	$f_2'(x_2)$	1	0.9	0.81	0.72	0.64	0.56	0.49	0.42	0.36	0.3
Iteration: 3											
State Variable	S_3	1	(1,2)	(1,2)	2	(2,3)	(2,3)	3	(3,4)	(3,4)	4
Stage Optima	$f_3'(x_3)$	1	0.9	0.81	0.729	0.648	0.576	0.512	0.448	0.392	0.343
Iteration: 4											
State Variable	S_4	1	(1,2)	(1,2)	(1,2)	2	(2,3)	(2,3)	(2,3)	3	(3,4)
Stage Optima	$f_4'(x_4)$	1	0.9	0.81	0.729	0.6561	0.5832	0.5184	0.4608	0.4096	0.3584

fractions representing warehouse on-time delivery. In the last iteration, the optimal fractions up to stage 3 are multiplied by fractions representing transportation providers' on-time delivery of trucks. The results are shown in table 1.

2.2. Classification of Levels for benchmarking delivery performance

The final iteration of DP problem provides optimal and sub-optimal values for benchmarking delivery performance. The current overall delivery performance of a firm and its supply chain is measured by multiplying the fractions representing suppliers' on-time and in full delivery, manufacturing schedule attainment, warehouse on-time and in full shipment and transportation providers' on-time delivery of trucks. The present performance may fall between any two values in the ranges specified for different classes of performance, i.e., Best in class, advantage, median or major opportunity.

Table 2. Classification of performance levels

S.No	Performance Class	Range for Delivery Performance
1	Best-in-class	80 % – 100 %
2	Advantage	60 % – 80 %
3	Median	40 % – 60%
4	Major Opportunity	Less than 40%

The classes of performance and corresponding range for delivery performance are given in the following table.

After assessing the performance of supply chain as a whole, the next bench mark level of expected overall delivery performance can be selected from stage - 4 optima in table: 1. Moving back from stage - 4, the combinations of expected performances at different stages could be bench marked. For example: suppose that the current overall delivery performance is between 0.6 and 0.8, it is in “ADVANTAGE” class. In order to achieve “BEST-IN-CLASS” performance for entire supply chain, the firms must work together to fix up norms for expected performance levels by different companies involved in the business. Now, the problem of fixing norms can be resolved considering costs associated with maintaining a desired level of performance by each entity as discussed in the following section.

2.3. Estimating optimal performance level (Total Cost Model)

Every firm along the supply chain can use this simple method to estimate the performance of its suppliers, internal operations, logistics providers, warehouses / distributors in terms of fractional success in achieving delivery performance. For each entity in the supply chain, i.e., a firm, its supplier, distributor and transporter, norms must be fixed while negotiating contracts. We can rank the entities depending on their past performances and form strategic alliances with only reliable parties. Every time, the bench mark should be revised with mutual agreement on terms and conditions of supply for smooth flow of materials along the supply chain with enhanced delivery performance to customers. Firms can carryout trade-off analysis while negotiating on definite level of performance expected from their counter parts considering the costs associated with maintaining desired level of performance and cooperation expected among the parties for effective achievement of the targeted performance level. But achieving desired level of delivery performance is associated with costs namely:

a) Supply Chain Management costs to maintain desired level of delivery performance. This cost Cd (associated with operating business activities to achieve desired level of performance) is directly proportional to 'P'. Where P= performance level expected.

b) Penalty associated with loss of sale or goodwill due to deficiency in delivery performance of the entity. This Cost Cp associated with loss of sale or good will due to deficient delivery performance is proportional to (1-P) / P.

Mathematically,

Cd α P (or)

$$Cd = Kd * P \tag{10}$$

Where Kd = slope of the delivery cost line

Also, we have Cp = 0 when P = 1

= ∞ when P = 0

Hence, we can take

Cp α (1 – P) / P (or)

$$Cp = Kp *(1 - P) / P \tag{11}$$

Total Cost TC = Cd + Cp

$$= Kd * P + Kp *(1 - P) / P \tag{12}$$

For minimum Total cost, the first order derivative of equation (12) should vanish. The resulting equation will give an expression for optimal performance level.

$$\frac{\partial(TC)}{\partial P} = K_d - \frac{K_p}{P^2} \tag{13}$$

$$\text{For } \frac{\partial(TC)}{\partial P} = 0, \quad P = \sqrt{\frac{K_p}{K_d}} \tag{14}$$

Equation (14) gives an optimal performance level for a combination of Kp & Kd.

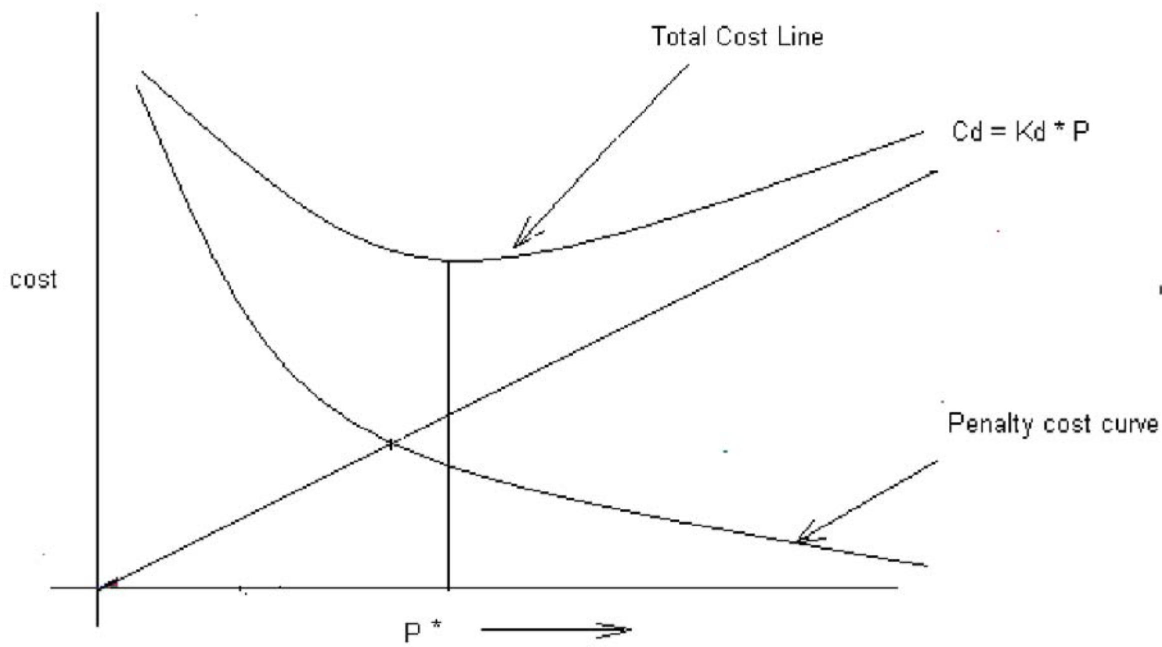

Figure 3. Graph indicating the relation between cost and performance level

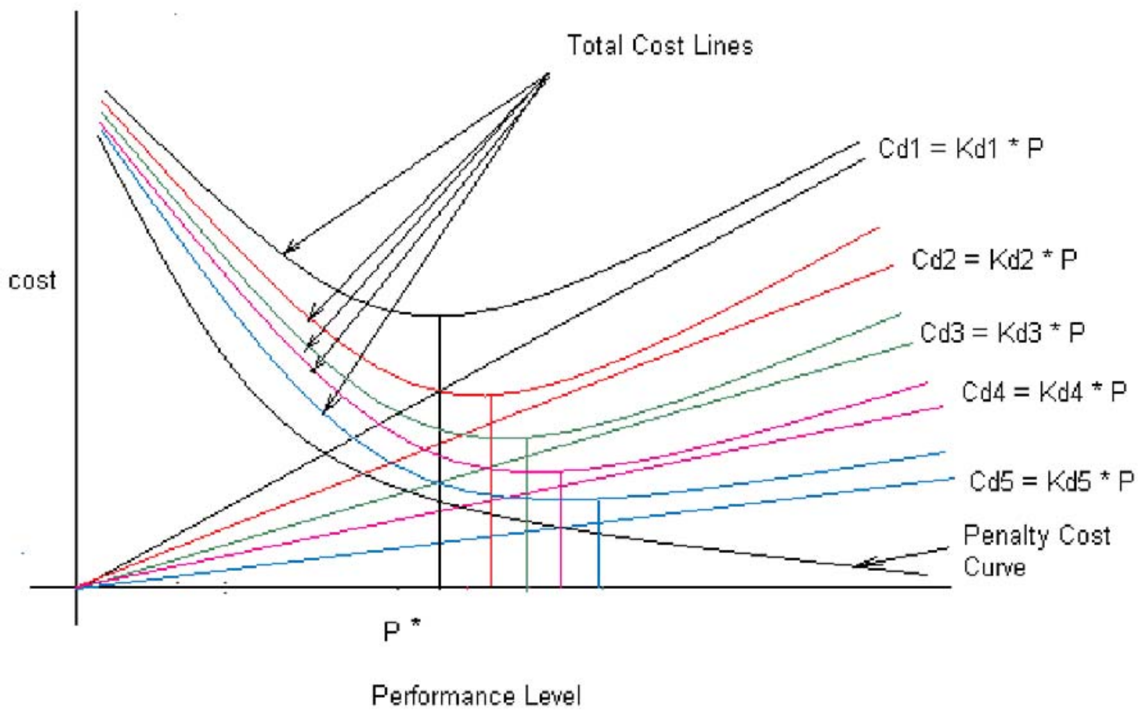

Figure 4. Graphical representation of variations in TC & P with slope of Cd line

Also $\frac{\partial^2(TC)}{\partial P^2} = \frac{2K_p}{P^3} > 0$ and hence the Total cost function is convex.

The relationship between performance level and associated costs are shown in the figure 3.

The graph clearly indicates that the optimal level of P is associated with minimum total cost. Depending on the core capabilities of SC partners, firms must arrive at a level of performance associated with minimum total cost.

2.4. Effect of Learning in delivery performance

As discussed earlier, initially the SC management costs will be significant but with little or no improvement. But as the supply chain matures, with the learning effect, the cost slope will come down. Assuming penalty cost curve to remain the same, decrease in slope of SCM cost (delivery cost) line, the minimum total cost tends to shift towards right indicating increase in optimal value of P but at a some what lesser total cost. The effect of learning has been explained graphically as shown in the figure 4.

The graph in the Figure 4, clearly shows that decrease in delivery cost slope leads to improved performance as well as minimum total cost. An empirical analysis has been carried out in the next chapter in support to the total cost model discussed in this session.

Creating a learning index utilizing learning rate metrics can be helpful for firms wishing to benchmark their supply chain's customer interface effectiveness (Kull et al., 2007).

Let us consider the following expression similar to that of Belkaoui (1986) for learning index:

$$P_n = P_o n^{\alpha} \qquad (15)$$

Where:
Pn = Performance after 'n' transactions
Po = Initial Performance level
α = Learning index = log Φ / log 2
Φ = Learning rate; $0 \leq \Phi \leq 1$.

While benchmarking, learning rate may also be used to fix up norms for trading partners.

3. DELIVERY PERFORMANCE OF BATTERIES MANUFACTURING FIRM

The firm produces industrial and automotive batteries of different capacities (Amp-hrs). The major raw materials lead and lead alloys (contributing about 74% of total material cost) were sourced from Australia and Korea. Among the other materials, separators contribute about 8.8% of the total material cost. In the present research work, the potential suppliers of these materials are only considered. Table 3 provide aggregate performance of supplier(s) in terms of fractional on-time delivery. The data furnished is on quarterly basis for simplifying analysis. The data required to calculate manufacturing schedule attainment of its Industrial Batteries division, automotive batteries division, power systems division, precision parts division put together is aggregated on quarterly basis and the furnished in table 4. The data regarding on-time and in full shipment to retail outlets as well as different customer segments such as railways, power sector, solar sector, telecom and automotive sectors put together aggregated on quarterly basis and presented in table 5. Also, the data regarding transportation providers' on-time delivery to

Table 3. Aggregate suppliers' on-time delivery performance on quarterly basis

Comparative statement of Suppliers' on-time delivery performance from 2004-10				
Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
2004 – 05	0.8133	0.8333	0.8100	0.9333
2005 – 06	0.9366	0.9100	0.9233	0.9300
2006 – 07	0.9233	0.8667	0.9000	0.8933
2007 – 08	0.9233	0.9000	0.8833	0.9167
2008 – 09	0.9000	0.9233	0.9033	0.9533
2009 – 10	0.9300	0.9233	0.9300	0.9600

Table 4. Aggregate manufacturing schedule attainments on quarterly basis

Comparative statement of % manufacturing schedule attainments from 2004-10				
Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
2004 – 05	0.9601	0.9741	0.9804	0.9838
2005 – 06	0.9896	0.9805	0.9752	0.9703
2006 – 07	0.9911	0.9917	0.9821	0.9878
2007 – 08	0.9965	0.9958	0.9941	0.9771
2008 – 09	0.9831	0.9605	0.9601	0.9683
2009 – 10	0.9626	0.9765	0.9360	0.9498

Table 5. Aggregate warehouse on-time shipments on quarterly basis

Comparative statement of % warehouse on-time & in full shipment from 2004-10				
Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
2004 – 05	0.7485	0.6499	0.7526	0.7078
2005 – 06	0.8375	0.8700	0.9087	0.9137
2006 – 07	0.9272	0.8791	0.8475	0.9190
2007 – 08	0.9143	0.8305	0.8636	0.9385
2008 – 09	0.9313	0.8917	0.8383	0.8542
2009 – 10	0.8202	0.8103	0.8667	0.8645

Table 6. Aggregate 3PL providers' on-time delivery on quarterly basis

Comparative statement of % warehouse on-time & in full shipment from 2004-10				
Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
2004 – 05	0.61	0.5767	0.6233	0.77
2005 – 06	0.70	0.5833	0.7433	0.8467
2006 – 07	0.7833	0.8200	0.8200	0.8167
2007 – 08	0.8333	0.8233	0.8267	0.8833
2008 – 09	0.8633	0.8767	0.8333	0.8400
2009 – 10	0.9033	0.8767	0.8467	0.8667

Table 7. Overall delivery performance of the supply chain on quarterly basis

Over all delivery performance from 2004 – 05 to 2009 – 2010				
Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
2004 – 05	0.3565	0.3042	0.3725	0.5004
2005 – 06	0.5434	0.4528	0.6081	0.6981
2006 – 07	0.6646	0.6196	0.6142	0.6623
2007 – 08	0.7009	0.6128	0.6269	0.7425
2008 – 09	0.7114	0.6933	0.6058	0.6623
2009 – 10	0.6632	0.6405	0.6388	0.6831

different customer segments / retail outlets have been furnished in aggregate on quarterly basis in table 6. Overall delivery performance of the firm and its supply chain is furnished in the table 7.

The graphs of delivery performance in the above table indicate that the mean / median performance is in between 0.6 to 0.8 in the past four years. Also, it is observed that the seasonal variations were mostly reduced in the current financial year (2009 – 2010).

The mean (0.6564) or median (0.6396) of the current year performance lies in between 0.6 to 0.8. This indicates that the firm and its supply chain are in "ADVANTAGE CLASS" as per classes of performance given in Table 2.

3.1. Benchmarking for overall delivery performance

Suppose the firm and its supply chain aim at achieving best-in-class delivery performance, the next bench mark level of performance is 0.81. In order to achieve Best-in-Class overall delivery performance, the mean / median performance in any aspect should not be less than 0.9. Even, within the same class (Advantage) the next benchmark level is 0.729. To achieve this, the expected level of performance in any aspect should not be less than 0.9.

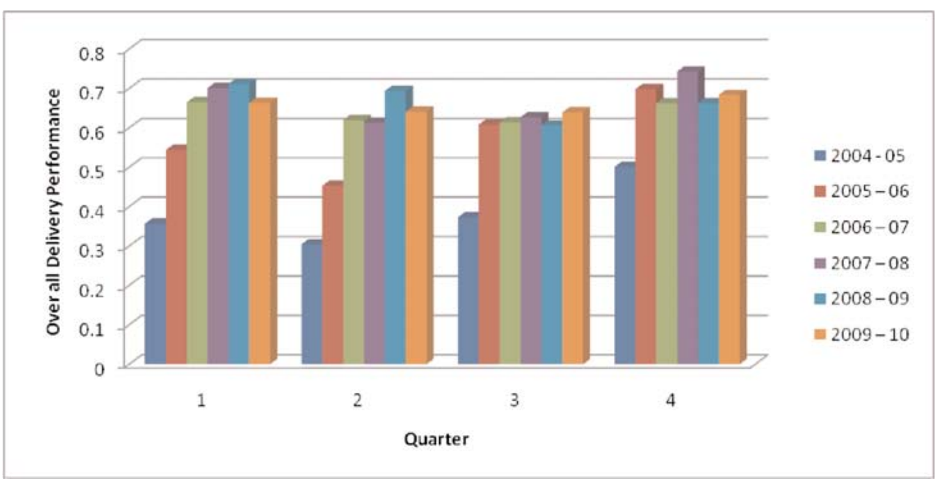

Figure 5. Overall Delivery performances of Batteries manufacturing Company

Hence, the firm and its trading partners must negotiate on maintaining desired levels of performance in a most coordinated and cooperative manner so as to improve the overall delivery performance.

3.2. Empirical analysis of total cost model

In general, the firms may not maintain relevant data on costs associated with inter-firm supply chain delivery performance. As real time data on penalty costs and delivery related supply chain management costs are not available, an empirical analysis has been carried out to check the validity of the total cost model.

Example: 1 Let us consider that the penalty cost coefficient Kp = 5 % of the value of transaction. Suppose the value of transaction is Rs: 20 lakhs. Then Kp = Rs: 100,000/-. Let the delivery related SCM cost be initially Rs: 250,000/-(i.e., about 12.5 % of the value of transaction). When this cost is reduced in steps of Rs: 10,000/- the corresponding changes in total cost as well as the optimal delivery performance as a result of 'learning effect' are given in table 8.

Note: In general, Total SCM costs are expressed as a % of Cost of Goods Sold which is about 5 – 10 % for best-in-class organizations. In this example delivery related SCM costs are alone considered for which industries may not maintain exclusive data. Hence, it is admitted that approximately higher value is taken.

The graph plotted for the penalty costs at different performance levels in example: 1 is a polynomial curve satisfying equation:

$$Cp = aP^2 + bP + c \text{ with } R^2 = 0.897$$

Table 8. Variations in performance level and total cost as a result of learning

Cost Slope K_d (Rs)	Optimum Performance Level	Optimum Total Cost (Rs)	Percentage Decrease in Total Cost	Percentage Increase in Performance level
250,000	0.6324	121367.77	---	---
240,000	0.6455	119468.67	1.565	2.071
230,000	0.6594	117593.02	1.570	2.153
220,000	0.6742	115743.94	1.572	2.244
210,000	0.6900	113927.54	1.569	2.344
200,000	0.7071	112132.71	1.575	2.478
190,000	0.7255	110385.98	1.558	2.602
180,000	0.7454	108696.16	1.531	2.743
170,000	0.7669	107085.10	1.482	2.884
160,000	0.7906	105546.21	1.437	3.090
150,000	0.8165	104123.97	1.348	3.276
140,000	0.8452	102835.19	1.238	3.515
130,000	0.8770	101725.09	1.080	3.762
120,000	0.9128	100833.02	0.877	4.082
110,000	0.9535	100226.77	0.601	4.459
100,000	1.0000	100000.00	0.226	4.877

(More Significant)

Where a = 17874; b = -27066 and c = 99340.

Similarly, for total cost:

$TC = a_1P^2 + b_1P + c_1$ with R^2 varying between 0.838 to 0.877

Where a_1 = 17874; b_1 = - 24566 to - 26066 (in steps of 1000 for reduction in Kd by Rs:10,000/-) and c_1 = 99340. The values

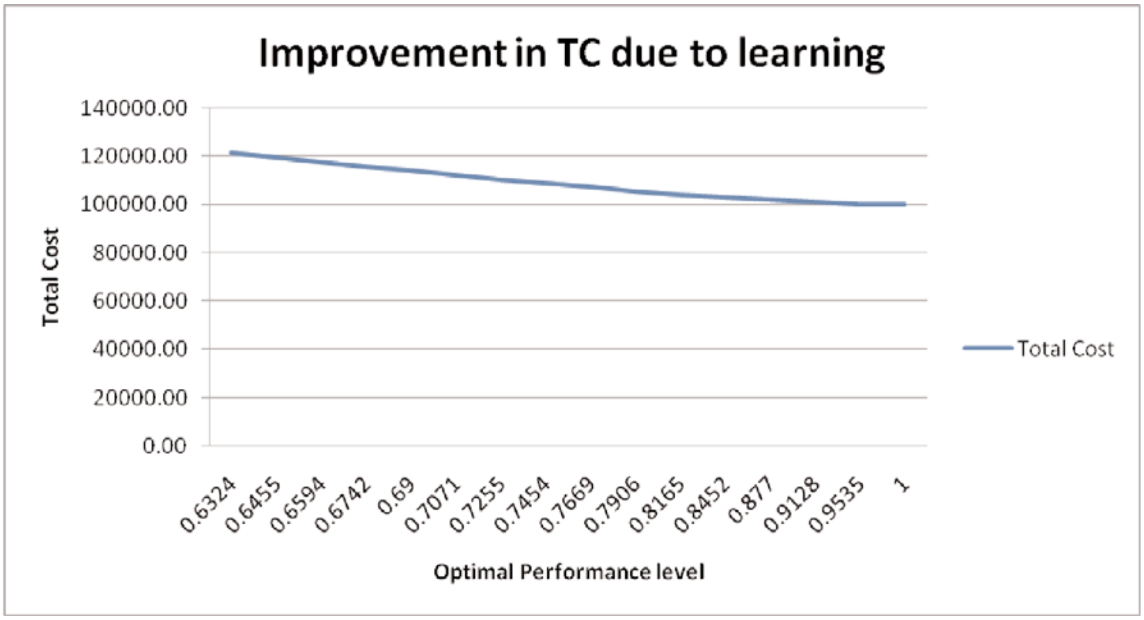

Figure 6. Improvement in Total Cost due to Learning

of R^2 indicating more significance of the selected costs (Cp & Cd) as good predictors of optimal performance levels with varying cost slope Kd.

The improvements in performance level and total cost with learning have been presented in the Figure 6.

This empirical analysis supports that the total cost model provides a basis for assessing performance of individual entities from overall supply chain perspective in achieving the desired delivery performance levels. Also, it demonstrates the importance of learning and helps firms to gain competitive advantage by exercising control on costs associated with SC delivery performance.

4. CONCLUSION

The methodology used in analysis is a step towards developing mathematical models for delivery performance measurement in an integrated supply chain practice. Companies may use this as a measure to bench mark their performance as well as the performances expected from their counter parts for successful supply chain management in terms of delivery performance. The analysis helps in providing bench mark values for expected performance levels of each entity in a supply chain to achieve desired over all delivery performance. Still there is wide scope for developing more complex mathematical models to analyze the cross border performance indicators using Operational Research tools for achieving performance excellence. Learning rate or learnability index may also be used as a metric to benchmark performance levels expected from each entity in a supply chain. As a whole, all such analyses provide guidelines for firms during negotiation on strategic agreements for chain wide performance improvements.

МЕРЕЊЕ ПЕРФОРМАНСИ ИСПОРУКЕ У ОКВИРУ МЕНАЏМЕНТА ИНТЕГРИСАНИХ ЛАНАЦА СНАБДЕВАЊА: СТУДИЈА СЛУЧАЈА У КОМПАНИЈИ КОЈА СЕ БАВИ ПРОИЗВОДЊОМ БАТЕРИЈА

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Извод

Перформансе испоруке дају индикацију о томе колико је успешан ланац снабдевања у довођељу производа и услуха до крајњег корисника. Ова мера је најважнија у менаџменту ланцима снабдевања јер интегрише мере перформанси почевши од снабдевача сировинама па све до крајњих корисника. Ово истраживање се заснива на студији случаја која је спроведена код водећег произвођача батерија (и акумулатора) у јужној Индији. У оквиру истраживања анализирају се елементарне перформансе у укупној перформанси испоруке читавог ланца снабдевања.Модели нелинеарног и динамичког програмирања су употребљени како би се добила оптимална и суб-оптимална решења, која ће помоћи компанијама у бенчмаркингу очекиваних нивоа перформанси.

Кључне речи: Ланац снабдевања, Перформансе испоруке, Бенчмаркинг и индекс учења

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