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MATHEMATICAL MODELS FOR DIFFUSION OF DRY TECHNOLOGY IN INDIAN CEMENT INDUSTRY

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ABSTRACT

The cement manufacturing process can be classified under three categories: wet process, semi-wet / semi-dry process and dry process. The substitution of wet process by dry process is a major energy saving and environmental friendly drive. The diffusion of dry manufacturing technology into Indian cement industry has been modelled using growth curve models and external – influence diffusion model. The saturation level for dry technology has been fixed as 90% as per availability of suitable raw materials for the use of dry technology in some parts of the country. The model parameters are estimated by linear regression on observed ratio of dry kilns to total number of kilns. A comparison of results obtained from different models suggests that logistic curve model provides better results than other diffusion models. L-89% logistic curve model is used to forecast the use of dry technology in Indian cement industry during 1999-2010. The model forecasts that 78.65% kilns would use dry technology by the year 2010.

Keywords: Indian cement industry, technology diffusion, growth curve models, external-influence diffusion model, dry process.

Introduction

The process of technological change is closely linked to innovation. A lot of things are invented, but it is only through innovation, that technology affects social change. The technological substitution phenomenon is based on the fact that a new technology that exhibits a relative improvement in performance or profit over an established one will eventually replace the old technology such as colour TV for black and white TV, calculator for slide rule etc. The diffusion process refers to the acceptance over time of a technology such as family planning devices, high yield variety seeds, and computer by individuals, groups or organisations (V. Peterka, 1977).

Although, scientific research and technological invention capabilities are critical factors in maintaining a dynamical technological base, transformation of these capabilities to economic wealth through a healthy and innovative manufacturing sector is a vital for long term economic survival. The organizations adopt a new technology when they believe that adoption will have a short term or long term payoff in profits. Recent dramatic changes in manufacturing systems and processes make it imperative for firms to follow current changes and future prospects. Delays in seizing technological opportunities may turn out to be very costly and in some instances, may even result in irreparable consequences for the survival of the firm. By being

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proactive rather than reactive to technological changes the organizations can influence their own future.

Over the last 160 years of the existence of cement, considerable technical advances have been made in the hardware and software of cement manufacturing. The industry has experienced an increasing emphasis on energy saving and environmental pollution control. The cement manufacturing process can be classified under three categories: wet process, semi-wet / semi-dry process and dry process. The oldest cement plants in India are based on wet process. Low technology, low capacity, high manpower and high-energy consumption characterize these plants. With the current trend towards higher capacity, lower energy consumption and better quality, the wet plants are being gradually converted or phased out. The process of semi-wet / semi-dry was evolved to encounter the high fuel consumption of the wet process. The fuel consumption by this process improves to about 900 to 1100 kcal / kg of clinker but it poses a number of operational and capacity problems. The dry process consumes significantly less energy and can often handle particulate emission problems more easily. The conversion of wet process by dry process is a major energy saving proposition. If the wet process capacity of 28378 tons per day converts into dry process it saves approximately 1.142 million tons coal per year (Report of the working group on cement industry, 1996).

The present study illustrates the diffusion of dry technology in Indian cement industry, by using the growth curve models and external-influence diffusion model. A comparison of the results obtained from these models is made. The best fitted model is used to forecast the diffusion of dry technology in Indian cement industry by the year 2010.

Diffusion Models

The technology diffusion literature focuses on the ‘process by which an innovation is communicated through certain channels over time among the members of a social system’ (Rogers, 1983). There are four key elements in the diffusion process: the innovation, channels of communication, time, and the social system. It is established that the diffusion of a successful innovation over time typically follows a sigmoid or S-shaped curve. The observed regularity in the diffusion process results from the fact that initially, during an embryonic phase, only a few members adopt the innovation. After embryonic phase the number of adopters increases rapidly over the time as the diffusion process begins to unfold more fully. Finally, during a maturing phase, the trajectory of the diffusion curve slows and begins to level off, and ultimately reaches an upper asymptote. Several investigators, Rapoport (1978), Mansfield (1961), Griliches (1957), Oster (1982) etc., have explained the S-shaped nature of diffusion processes.

Although most of the innovations show S-shaped diffusion curve, but the exact nature of the curve including its slope and asymptote may differ for each of the innovation. The slope of the curve indicates the pace of the diffusion. A steep slope shows rapid diffusion while gradual slope shows relatively slow diffusion. The following diffusion models are considered in the present study:

Growth Curve Models

The term growth curve represents a loose analogy between the growth in performance of a technology and the growth of a living organism. Despite some attempts to make the analogy rigorous, it is at best a causal one. Nevertheless, the term growth curve is descriptive and evokes an image of a pattern of technological change. Growth curves are frequently used to forecast the substitution of one technology for another, as well as for forecasting improvement in technical approaches (Martino, 1972).

Forecasting by growth curves requires fitting a mathematical formula for a growth curve to a set of historical data. The fitting is usually done using linear regression (least square). Once a mathematical formula has been fitted to the data, extrapolating that curve to the years beyond the historical data makes the forecast.

One common formula for a growth curve is the Pearl or logistic curve, named after the American demographer Raymond Pearl, who popularized its use in demographic forecasting. The logistic curve is the most widely used functional and it is a genuine S-shaped curve. The formula for logistic curve is

$$Y = \frac{S}{1 + c_0 e^{-c_1 t}}$$

where S is an upper limit to the growth of the variable represented by Y, c_0 and c_1 are the coefficients evaluated by fitting the curve to the data , and e is the base of the natural logarithm. The inflection point of this curve occurs at time $t=(\ln c_0)/c_1$, when Y= S/2. The curve is symmetrical about the point, when the upper half being a reflection of the lower half.

Another frequently used growth curve is the Gompertz curve, named after Benjamin Gompertz, English mathematician. The equation for the Gompertz curve is $Y = Se^{-c_0 e^{-c_1 t}}$. This curve is not symmetrical. The inflection point occurs at time $t = (\ln c_0) / c_1$, where Y = S/e. Just as with the logistic curve, it is necessary to estimate coefficient c_0 and c_1. Once c_0 and c_1 are obtained from the regression, they can be substituted in the formula to forecast Y for future time periods.

External–Influence Diffusion Model

The models specified above are based on diffusion patterns in terms of pre-specified trend or distribution function. However, because any unimodel distribution function will generate an S-shaped curve, it is often not possible to empirically determine which of several competing trend or distribution functions best describes a given diffusion curve. Therefore, attempts have been made to develop theory-based “diffusion models” for analyzing and modelling the diffusion of a technology in a social system over time (Mahajan and Peterson, 1985).

The rate of diffusion of a technology at any time t is directly proportional to the gap between the total number of possible adopters and the cumulative adopters existing at that time. Hence the rate of diffusion at time t can be expressed as follows:

$$\frac{dN(t)}{dt} = g(t)[S - N(t)] \qquad (1)$$

where N(t)=cumulative number of adopters at time t

g(t)=coefficient of diffusion

S=total number of potential adopters at time t

dN(t)/dt =rate of diffusion at time t.

It is evident from the model that as the cumulative number of adopters, N(t), approaches the total number of possible adopters, S, the rate of diffusion decreases. The relationship between the rate of diffusion and the number of target adopters at time t, [S-N(t)], is controlled by g(t), the coefficient of diffusion. The value of g(t) depends on such characteristics of the diffusion process as the nature of the innovation, communication channels employed, and the attributes of the social system (Jain et al., 1991).

If the technology is communicated in the society through external factors like government agencies, consultants, media etc., then g(t) can be treated as a constant, say 'a'. The resultant diffusion model with g(t)=a is referred as external-influence diffusion model (Coleman et al., 1966). If the diffusion process takes place though interpersonal contacts then g(t) can be replaced with bN(t) and the resultant model is termed as the internal-influence diffusion model (Mansfield, 1961; Griliches, 1957; Gray, 1973). Finally, if external factors and interpersonal contacts both are involved in the diffusion process, then g(t) is replaced with [a+bN(t)] and the model is referred as the mixed-influence diffusion model (Bass, 1969).

Data

The data were collected from publications of the Cement Manufacturing Association (CMA), India. There were only 18 kilns based on dry technology in the year 1970 in India and this number had increased to 113 in the year 1998. The year-wise profile of dry technology is given in Table 1.

Table 1: The profile of dry technology in Indian cement industry

Year	Reference Time (t)	Dry Kilns	Total Kilns	Dry/Total Kilns
1970	0	18	119	0.151261
1983	13	50	154	0.324675
1992	22	86	163	0.527607
1993	23	91	168	0.541667
1994	24	91	160	0.56875
1995	25	97	166	0.584337
1996	26	102	171	0.596491
1997	27	108	176	0.613636
1998	28	113	180	0.627778

Estimation of Model Parameters

The parameters involved in the diffusion models discussed in section 2 were estimated using the data shown in Table 1. It is assumed in the growth curve models that the saturation level S of dry technology is 0.9 (i.e. 90%) because, the raw material available in some parts of India is not suited for dry technology. The parameters c_0 and c_1 are calculated by fitting the curve with observed data in both the cases. Let R (t) represents the ratio of dry kilns to total number of the kilns at time t, then the growth curve models for the diffusion of dry technology in Indian cement industry can be written as follows using estimated values of the parameters:

Logistic Curve Model

$$R(t) = 0.9 / (1 + 5.13459 \times \text{Exp.}(-0.0891 \times t)) \qquad (2)$$

$R^2 = 0.997$

Gompertz curve model

$$R(t) = 0.9 \times \text{Exp.}(-1.917457 \times \text{Exp.}(-0.0588 \times t)) \qquad (3)$$

$R^2 = 0.989$

External–influence diffusion model

The diffusion process of dry technology in cement industry is influenced by the government agencies, consultants, environmental requirements etc. Therefore, an external–influence diffusion model may be appropriate for diffusion of dry technology in Indian cement industry. The external–influence diffusion model for the present study is derived from the equation (1) by replacing g(t) and N(t) with a and R(t) respectively as follows:

$$\frac{dR(t)}{dt} = a[S - R(t)] \qquad (4)$$

where,

R(t) = Ratio of dry kilns to total number of kilns at time t

S = Upper limit of the ratio R(t)

dR(t)/dt = Rate of change of ratio R(t) at time t

a = an index or coefficient of external influence emanating from out side of the industrial system.

On solving the external–influence diffusion equation (4), we have

R(t) = S-(1/exp(at+b)) (5)

The parameters a and b are evaluated numerically through linear regression analysis using data on ratio of dry kilns for the period 1970-98 from Table 1. The upper limit S is taken as 0.9 as in earlier cases. The estimated values of parameters are: a = 0.03725 and b = 0.206 with R^2 = 0.964. The model equation (5) can now be rewritten as

R(t) = 0.9 - (1/exp(0.03725t+0.206)) (6)

Forecasting

The logistic curve model (2), Gompertz curve model (3) and external-influence diffusion model (6) are used separately to calculate R(t) for the time period 1970-98. The results obtained are listed and compared with observed ones in Table 2. Mean square error (MSE) is evaluated from the results of each model for the time period 1970-1998 and also listed in Table 2. Figure 1 shows graphical comparison of the results obtained from these models and the known ratios. The Table 2 and Figure 1 show that the logistic curve model best fits the observed data. Hence logistic curve model is used for forecasting the diffusion of dry technology.

Now, in order to assess the minimum requirement of observed data points for forecasting with the logistic model, we take the first four data points to estimate the parameters. After estimating the parameters, forecasts are made for remaining time periods and then compared the computed forecasts with the observed ones. Next, we take the first six data points, then first eight, and at last all nine data points.

Logistic curve models with their respective percentages of conversion can be illustrated as

I. L-44% refers logistic curve model that uses 44% of data points for establishing the trend. The model with estimated parameters will be R (t) = 0.9 / (1+ 5.13459 ´ Exp. (- 0.0885 t)) with R^2 = 0.996

II. L-67% refers logistic curve model that uses 67% of data points for establishing the trend. The model with estimated parameters will be R (t) = 0.9 / (1+ 5.170658 ´ Exp. (- 0.0898 t)) with R^2 = 0.997

Table 2: Comparison of growth curve models

Reference Time (t)	Ratio of dry kilns with total number of kilns			
	Observed	Logistic	Gompertz	External-Influence
0	0.1513	0.1467	0.1323	0.0862
13	0.3247	0.3445	0.3686	0.3985
22	0.5276	0.5223	0.5319	0.5414
23	0.5417	0.5417	0.5481	0.5545
24	0.5688	0.5607	0.5639	0.5671
25	0.5843	0.5793	0.5791	0.5793
26	0.5965	0.5975	0.5939	0.5910
27	0.6136	0.6151	0.6082	0.6023
28	0.6278	0.6322	0.6219	0.6132
MSE		0.0001	0.0003	0.0012

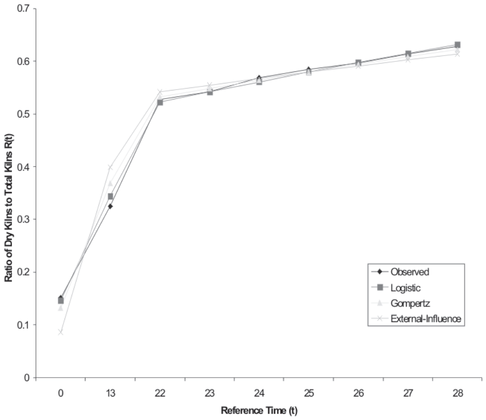

Figure 1: Comparison of the models' results with observed data

III. L-89% refers logistic curve model that uses 89% of data points for establishing the trend. The model with estimated parameters will be R (t) = 0.9 / (1+ 5.15517 ´ Exp. (- 0.0894 t)) with $R^2 = 0.997$

IV. L-100% refers logistic curve model that uses all data points for establishing the trend. The model with estimated parameters will be R (t) = 0.9 / (1+ 5.13459 ´ Exp. (- 0.0891 ´ t)) with $R^2 = 0.997$.

The comparison of the results obtained from logistic curve models with different conversion factors is shown in Table 3 and Fig. 2. The comparison of results clearly indicates that the logistic curve model with 89% of data points best fits with the observed ratios of dry to total kilns. Therefore, L-89% logistic curve model is used to forecast the diffusion of dry technology in Indian cement industry during 1999-2010. The forecasted ratios listed in Table 4 show that 78.65% of kilns would have dry technology by the year 2010.

Results and Discussion

The diffusion of dry manufacturing technology in Indian cement industry has been modelled using growth curve models - logistic and Gompertz and an external–influence diffusion model.

Table 3: Comparison of the results from logistic curve models with different conversion factors

Reference Time	Observed R(t)	R(t) with different conversions		
		L-44%	L-67%	L-89%
0	0.151261	0.1467	0.1459	0.1462
13	0.324675	0.3429	0.3450	0.3445
22	0.527607	0.5194	0.5242	0.5229
23	0.541667	0.5387	0.5437	0.5423
24	0.56875	0.5577	0.5628	0.5614
25	0.584337	0.5762	0.5815	0.5801
26	0.596491	0.5943	0.5997	0.5982
27	0.613636	0.6119	0.6174	0.6159
28	0.627778	0.6290	0.6345	0.6330
MSE		6.94E-05	6.34E-05	6.10E-05

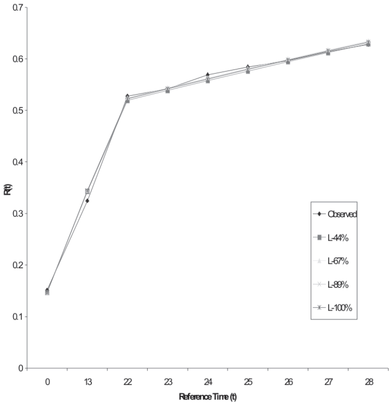

Figure 2: Comparison of the Logistic curve models with different conversion factors

The saturation level for dry technology has been fixed as 90% as per availability of suitable raw materials for the use of dry technology in some parts of the country. The model parameters are estimated by linear regression on observed ratio of dry kilns to total number of kilns. A comparison of results obtained from different developed models suggests that logistic curve model provides better results than other diffusion models. Therefore, Logistic curve model is used to forecast the diffusion of dry technology.

A requirement of minimum number of observed data points for forecasting with logistic curve model is assessed. Different sets of data points are used to estimate the parameters and then forecasted values are compared with the observed ones. It is found that minimum 89% of data points are needed to make better forecast. Therefore, L-89% logistic curve model is used to forecast the use of dry technology in Indian cement industry during 1999-2010. The model forecasts that 78.65% kilns would use dry technology by the year 2010.

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Table 4: Forecasted Ratio (Dry Kilns /Total Kilns) using L-89% logistic curve model

Year	Ratio of Kilns (Dry/Total)
1999	0.649474
2000	0.665312
2001	0.680487
2002	0.694984
2003	0.708792
2004	0.721908
2005	0.734335
2006	0.74608
2007	0.757154
2008	0.767573
2009	0.777355
2010	0.786521

References

- Annual reports of CMA for the years 1980-2000. Published by Cement Manufacturing Association (CMA), India.
- Bass, F.M. (1969) A new product growth model for consumer durables. *Management Science* 15, 215-227.
- Coleman, J.S., Katz, E. and Menzel H. (1966) Medical innovation: a diffusion study. Indianapolis: Bobbs-Merill.
- Gray V, (1973) Innovation in the states: a diffusion study. *The American Political Science Review* 67, 1174-1182.
- Griliches Z. (1957) Hybrid corn: an exploration in the economics of technological change. Econometrica 25, 501-522.
- Jain A., Rai L.P., Sharma S and Bhargava S.C. (1991) Modelling technology diffusion – its basis and applications to Indian Market. *Journal of Scientific and Industrial Research* 50, 496-515.
- Mansfield E. (1961) Technical change and the rate of imitation, Econometrica 29, 741-766.
- Martino, J.P. (1983) Technological forecasting for decision making. New York: Elsevier North-Holland.
- Oster S. (1982) The diffusion of innovation among steel firms: the basic oxygen-furnace. Bell J. Economics 13, 45-56.
- Rapoport, J. (1978) Diffusion of technological innovation among nonprofit firms: a case study of radioisotopes in U.S. hospitals. J. Econ. Business 39, 108-118.
- Report of the working group on cement industry (1996), IXth Five Years Plan (1997-2002), prepared by NCB and CMA for the Planning Commission of India.
- Rogers, E.M. (1983) *Diffusion of innovations. New York: Free Press.*
- V. Peterka (1977) Macrodynamics of technological change: market penetration by new technologies. Tech. Rep. 7722, IIASA, Luxemburg.
- Vijay Mahajan and Robert A. Peterson (1985) *Models for innovation diffusion. SAGE Publications, New Delhi,*