WORKING PAPER NO.285

Longitudinal Studies for Measuring Sequence of Cumulative Capability Building Measures – An Operations Strategy Perspective

By

Debabrata Ghosh

March 2009

Please address all your correspondence to:

Debabrata Ghosh
Doctoral Student (Producting & Operations Mgmt)
Indian Institute of Management Bangalore
Bannerghatta Road
Bangalore – 560 076
e-mail: debabratag07@iimb.ernet.in

LONGITUDINAL STUDIES FOR MEASURING SEQUENCE OF CUMULATIVE CAPABILITY BUILDING MEASURES – AN OPERATIONS STATEGY PERSPECTIVE

Debabrata Ghosh

Doctoral Student (Production and Operations Management.)

Indian Institute of Management, Bangalore

E-mail: debabratag07@iimb.ernet.in

ABSTRACT

Several articles have been written in the past examining performance improvement paths and various forms of efficiency frontiers in operations strategy for Industries in US and Europe. There have been weaknesses in these studies owing to their cross sectional nature. In this paper, we bring out those weaknesses; discuss the strength of longitudinal studies and develop a framework to *empirically verify* the sequence of cumulative capability building measures in industries. The verification or refutation of the 'sandcone model' (Ferdows and De Meyer, 1990) through this study will bring forth new directions of future research for Industries operating in India.

Key Words: operations strategy, performance improvement paths; cumulative capability building measures; cross-sectional methods; longitudinal studies; trade-offs; regression; strategy.

INTRODUCTION

The 1970's saw a paradigm shift in the field of operations strategy when Skinner (1969) talked about viewing manufacturing as a pillar of strategic strength, which can be aligned to the larger business goals in order to achieve superior manufacturing capability and competitive advantage. His seminal work looked at aligning the manufacturing goals with the business strategy of a firm through the *trade off model.* The model describes achieving manufacturing goals through tradeoffs between specific capabilities like cost vs quality or dependability vs flexibility. Skinner professed the achievement in any one of these capabilities at the cost of the other.

However, it was increasingly realised that many companies, particularly the Japanese automobile manufacturers engaged themselves in quality improvement programs and simultaneously reported lower costs (Hayes and Pisano, 1994). Various companies started bringing in new models and products with changing customer demands while keeping high standards of quality. The trade off models were not applicable here. Observations made by researchers, Ferdows et.al (1986), Miller et. al (1989) hinted that several manufacturers used a multitude of different approaches and not tradeoffs, for developing such capabilities which was termed as *simultaneous capabilities.* Compared to their competitors they were able to have better quality, were more dependable, responded faster to changing marker requirements and inspite of all that, achieved lower costs (Ferdows and De Meyer, 1990). Many North American, Japanese and European companies followed a distinct sequence of improvement programs which aimed at building one capability upon another and not one *instead* of another. Thus, the focus gradually shifted from tradeoffs to building cumulative capabities in manufacturing. However the researchers were not able to invalidate the tradeoffs completely.

Hence the literatures of this period depict the dichotomy between trade off model and cumulative capability building measures. Several studies soon found the conditions for existence of both trade off models and cumulative models (Ferdows and De Meyer, 1990; Rosenzweig and Roth, 2004). The researches next focussed on finding the correct *sequence* of measures for building manufacturing capability. Which path should a firm follow for sustainable competitive advantage? Following this, Ferdows

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and De Meyer (1990) professed the need to have a fresh re-examination of whether there was a need to avoid the common trade-offs in production. The essence of their paper is that excellence is built on a common set of fundamental principles which are easier to get in place starting with one particular type of activity, and then pursuing other activities that expand and enrich this set of principles. The *sequence* is important because it is the combination of organizational priorities which form the best vehicle for enhancing the appropriate foundation principles. They proposed their famous *Sand Cone model* based on the *Cumulative Model* proposed by Nakane (1986). The *sand* being the management effort and resources, the company has to first build the base of the model through quality improvement programs, then build up dependability, speed and finally cost improvement measures($Q \rightarrow D \rightarrow F \rightarrow C$); however through this entire build up, the base and the subsequent layers have to be developed continuously.

Several researchers went ahead to empirically validate this model, particularly the sequence of the model (Rosenzweig and Roth, 2004; Flynn and Flynn, 2004; Gyampah and Meredith, 2007; Lapre and Scudder, 2004). In the researches that followed several *cross sectional* studies were done to empirically validate the sand cone model (Rosenzweig and Roth, 2004; Flynn and Flynn, 2004; Gyampah and Meredith, 2007) and the sequence necessary for building cumulative capabilities in manufacturing industries. Most of these researches failed to validate the complete model while acknowledging the weakness of their work based on cross sectional study rather than longitudinal studies.

The following paper presents a longitudinal study based framework for analysing the cumulative capability building model. The paper supports the longitudinal study in specific empirical investigations such as this and cites the reasons for the same. It also brings out certain weaknesses of the cross sectional data in the previous studies done. The paper has been divided as:

In the next section we describe the improvement paths for bettering the performance of a company; in the third section we discuss the various research works in this field; in the fourth section we compare cross sectional studies and longitudinal studies and bring out the advantage of using longitudinal studies in the present research context, we also present the framework suggested for carrying out longitudinal studies. We conclude the paper by discussing the implications of the present study and the future research potential.

PERFORMANCE IMPROVEMENT PATHS

Several researches have provided different names to the cumulative capability building process, namely: 'process of competitive progression' (Rosenzweig and Roth, 2004); 'Improvements in manufacturing performance' (Ferdows and De Meyer, 1990) and 'Performance Improvement Paths' (Lapre and Scudder, 2004). I term it 'Performance Improvement Path' because improvement journey is not a destination, its nature is cumulative and it progresses through time. It's a path and hence I would call it so. Cumulative capability building and the improvement path has been shown in appendix A.

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Insert Fig 1 about here

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The diagram combines the various ideas presented in different literature (Skinner, 1969; Lapre and Scudder, 2004) and should help understand the concept of trade offs and cumulative capability building measures. We justify the 'time dependency' of this model from the following discussion. Let Firm 1 be in position A (see figure 1), where the curve LL depicts the performance frontier (or productivity frontier) as described by Porter (1996). It is the best possible frontier of operating a firm given a certain technology and operational strategy of a 'winning' firm. The winning firm could be a cost competitor or differentiator and is an industry leader. Clearly position A is a below par performing firm as compared to another firm operating near the frontier. For firm 1 to move from region A to region B, a certain operational strategy is required which must align with the business strategy of its corporate. But more importantly the firm can adopt cumulative capability building measures and not tradeoffs which mean that the firm can cumulatively improve upon its performance metrics like quality, cost, delivery and flexibility. The reason being it must be underperforming in all or any other combination of the same factors. There is slack present in the company. This improvement is not immediate and requires consistent effort from the organization as a whole. Also, the best way to reach the performance frontier is to benchmark the firm against the industry leader.

[A]: Thus the movement of the Firm 1 from region a to region b is a time consuming process.

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Once the firm has reached region B, it stands as an industry leader in terms of few or all of its performance metrics. But it is a continuously improving phenomenon and is as dynamic as the market in which it exists. Hence even at B the firm 1 has to work on its improvement programs. It can now choose to improve further on its performance metrics and since the firm is not operating under any slack, it faces *trade off*. E.g. in region B the firm decides to improve quality further and hence in that case it has to trade off between cost and quality and it improves quality further with increased investments (cost). Thus it moves to region C.

[B]: This present process also consumes time and only trade-offs are involved here.

There are new entrants into business quite frequently and in a dynamic and competitive environment, the performance frontier may also shift owing to a significant change in the technology or a new innovative approach by any of the firms. Owing to the shift in the performance frontier as shown in the Appendix A, the firm1 may either have to shift from region C to region D or region B to region D. In either case it falls behind the industry leader who is at the new frontier and the firm now has to develop strategies again for traversing to the new frontier which is also:

[C] A time based process.

From the above discussion, we conclude through *[A]*, *[B]* and *[C]* that performance *improvement paths are significantly time dependent* and hence a time dependent analysis is required for studying such firms. We also observe that sustainability of the performance of a firm depends on the path it chooses and since this path has temporal dimensions, longitudinal studies are an absolute necessity.

LITERATURE REVIEW

The above section explained the existence of both the trade off model and cumulative capability building model under different circumstances. In this section, we analyse some of the previous works done to find the path dependency of the sandcone model. Rosenzweig and Roth (2004) used analytical path model to test the cumulative capability building model. They introduced other variables like 'operational know how' and 'non value added activities' to the model. Through their work they demonstrated that Quality as an improvement program directly affects delivery, delivery directly affects flexibility, and flexibility directly helps achieve lower costs. They also demonstrated that interchanging volume flexibility and dependability did not improve the present model so they continued with the sequence of sandcone model. However as the authors acknowledge themselves they were not able to demonstrate *causality* i.e. the basic question of whether capability building measures are path dependent or not could not be answered. Can we say that quality development is the first step to capability building followed by development of dependability, flexibility and lower cost? Does each step precede the other? The study could not show that. In their study the authors use questionnaire based approach and collect data from high tech firms at a single point of time. The authors recognise it as a potential source of limitation in their study and suggest longitudinal research.

Flynn and Flynn (2004) in their study hypothesized various relationships in the cumulative capability building domain but found no evidence in support of the Ferdows and DeMeyer's (1990) sandcone model. They stated that cumulative capability building measures are highly contingent on industry and country. It's not a one size fit all model. They criticise the sandcone model stating that the sequence may not be universally applicable to all industries and market conditions. The authors also state that the research is cross-sectional in nature and allows limited test of the sequential model of cumulative capabilities. They suggest longitudinal research for further analysis. Thus, both the above models acknowledge the importance of longitudinal research in this domain.

In another work by Gyampah and Meredith (2007), a cross sectional study was conducted in the underdeveloped economy of Ghana, and it was found that the Ferdows and DeMeyer model was not followed and the first emphasis was on quality and the next on cost. The authors also suggest that the capability building measures

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undertaken by the manufacturing firms at Ghana may be dependent on the economic factors at Ghana. The authors however acknowledge that the cross sectional nature of the study cannot be used to infer cause and effect in terms of the dependencies between capabilities.

As one of the few studies done using longitudinal method, Lapre and Scudder (2004) traced the performance of U.S. Airline Industry from 1987 to 1998. They answer the two questions, namely: Should improvement be attempted in one dimension or multiple dimensions and what dimensions should firms improve first and second and so on? The first question is answered previously through discussions on conditions of trade offs and cumulative capability building measures. The next question was answered by the authors through their findings and a plot of quality vs cost of the airlines over the study period. The findings were that quality was a definite initiative which precedes cost improvement measures. In one way it does confirm one aspect of the sandcone model that quality is an initial measure for lasting improvements in manufacturing. However dependability and speed as the other two steps in the sequence could not be confirmed because of lack of measures for them in the data collected through the U.S Department of Transportation. Although their work could be considered as one of the first attempts to analyse the sandcone model through longitudinal studies, their study was restricted to quality as the first step to building cumulative capability. Our paper builds on this further and analyses dependency of other capability building measures.

Clearly, *path dependence* or sequencing of cumulative capability building measures remains an elusive subject. The various research works have analysed sandcone model with varying outcomes. The researches dealing with cross sectional methods were unable to detect any path dependency and recognise a serious weakness in their studies of that of the absence of longitudinal studies. We also find that significant work has not been done with longitudinal methods. Researchers have discussed various processes needed to achieve cumulative capability building measures but they have not been able to identify the correct sequence of measures. Secondly, cross sectional data may not provide the *causality* researchers are looking for in this chain of capability building measures. We discuss the shortcomings of cross sectional methods in the next section.

THE CUMULATIVE CAPABILITY BUILDING MEASURES

The notion of cumulative capability building is a complex phenomenon and may follow a sequence of steps where quality is one of the primary phenomena. What follows that is still not proven. Why have studies so far failed to convincingly prove the path dependence of capability building measures? Or is any such sequence highly contingent on the market conditions in which the firm operates, the industry to which it belongs, the country in which it is set up and the culture which it fosters. We would from here divide the discussion in two parts: the first part would discuss longitudinal study approach and second would discuss a framework for investigating cumulative capability building measures.

Longitudinal Study Approach

We present a comparison of the cross sectional studies and longitudinal studies in this section. A cross-sectional study is a descriptive study in which variables are measured simultaneously in a given population. Cross-sectional studies can be thought of as providing a "snapshot" of the characteristics of a process in a population at a particular point in time. This type of data can be used to assess the prevalence of certain conditions in a population. However, since the status of the two variables are measured at the same point in time, it may not be possible to distinguish which variable proceeded or followed the other, and thus cause and effect relationships are not certain. Cross-sectional analysis studies the relationship between different variables at a point in time. Unlike time series, cross-sectional analysis relates to how variables affect each other at the same time. This is the primary reason why the previous studies have failed to analyse *causal relationships* between the variables under study in the sandcone model.

Andrew M. Pettigrew (1990) in his work on longitudinal research for studying organisational change professed that longitudinal methodology provides the opportunity to examine continuous processes and to draw in the significance of various interconnected level of analysis. Thus there is a scope to reveal the multiple sources and loops of causation and connectivity so crucial in indentifying and explaining the patterns in the process of change. He also reported that time series data on the birth, evolution, impact and fate of internal consultancy groups reported in Pettigrew(1975) illustrates how judgements of impact and fate are sensitive to time

and the vagaries of shifting internal and external contexts. The author further states that related to the core question of what change means in longitudinal research, there is the equally important issue of the meaning of time in temporal analysis. The author states that as Elchardus (1988) has argued, "time is increasingly recognised as an issue in its own right and not just a secondary factor that becomes relevant when the question of social change is raised". In our context it's the *industrial change* we are dealing with and owing to the arguments stated above, longitudinal studies to analyse the path dependency of sandcone model becomes increasingly important.

In another work on Longitudinal research methods the authors Van de Ven and Huber (1990) state that any study of organisational change focuses on two questions:

1) What are the antecedents or consequences of changes in organisational forms?

2) How does an organisational change emerge, develop, grow or terminate over time?

It's the second question that we try to answer in our context. The time dependent property of the present research context makes it highly contingent on longitudinal studies. In contrast, *causality* cannot be tracked through cross sectional data because it gives no idea of antecedents and consequences of the actions taken. Hence longitudinal studies are the prevalent methods to use in this research context.

Table 1: The table summarises the differences between cross sectional studies and longitudinal studies:

	Time Period of Study	Relationship between variables under study	
Cross Sectional Studies	Single point of time	Causal relationship	Antecedents and precedents difficult to gauge
Longitudinal Studies	Over a period of time	Cause and effect relationship	Antecedents and precedents are observable

Framework for Longitudinal Studies

In this section framework for longitudinal studies is developed. Cross sectional studies may not be enough to dissect this relationship between the measures. As we have seen such studies have established significant effect of one factor over another

but failed to establish the sequence of measures. Having established the inadequacy of the cross sectional data based approach, we present a generic framework to use longitudinal study in the present context. The framework is shown in appendix B.

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Insert Fig 2 about here

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Step 1: Indentify constructs for each of the performance metrics quality, dependability, flexibility and cost. For this study we use the same constructs as used by Rosenzweig and Roth (2004).

Step 2: Identify the dataset for empirical investigation. Use the database of companies for analysis in India keeping 10 years as the study period.

Step 3: Conduct validity and reliability tests for the constructs.

Step 4: Refine the measures based on the reliability and validity tests.

Step 5: Once the tests are cleared, the final instrument is ready for measuring the constructs.

Step 6: Conduct statistical tests on the measures of the constructs. The various tests can be multiple regression and logit regressions. *Stepwise regression should be used to determine the order of significant predictor variables for each dependent variable.* It can be re-checked using stepwise forward and stepwise backward regression. Since, all the variables were measured on the same scale (degree of emphasis); we can use the standardized β coefficients to indicate the *relative* importance of the multiple independent variables in predicting the dependent variable. The strength of the association between the dependent and independent variables is indicated by the R^2 values.

The regression equations could be:

$$C_t = \beta_0 + \beta_1 X_{Qt} + \beta_2 X_{Qt-1} + \beta_3 X_{Qt-2} + \beta_3 X_{Qt-3} + \ldots\ldots\ldots + \beta_n X_{Qt-n}$$
$$+ \beta'_1 X_{Dt} + \beta'_2 X_{Dt-1} + \beta'_2 X_{Dt-2} + \ldots\ldots\ldots + \beta'_n X_{Dt-n}$$
$$+ \beta''_1 X_{Ft} + \beta''_2 X_{Ft-1} + \beta''_3 X_{Ft-2} + \beta''_3 X_{Ft-3} + \ldots\ldots\ldots + \beta''_n X_{Ft-n}$$
$$+ \beta'''_1 X_{Ct} + \beta'''_2 X_{Ct-1} + \beta'''_3 X_{Ct-2} + \beta'''_3 X_{Ct-3} + \ldots\ldots\ldots +$$
$$\beta'''_n X_{Ct-n}$$

$$F_t = \beta_0 + \beta_1 X_{Qt} + \beta_2 X_{Qt-1} + \beta_3 X_{Qt-2} + \beta_3 X_{Qt-3} + \ldots\ldots\ldots + \beta_n X_{Qt-n}$$
$$+ \beta'_1 X_{Dt} + \beta'_2 X_{Dt-1} + \beta'_2 X_{Dt-2} + \ldots\ldots\ldots + \beta'_n X_{Dt-n}$$
$$+ \beta''_1 X_{Ft} + \beta''_2 X_{Ft-1} + \beta''_3 X_{Ft-2} + \beta''_3 X_{Ft-3} + \ldots\ldots\ldots + \beta''_n X_{Ft-n}$$

$$D_t = \beta_0 + \beta_1 X_{Qt} + \beta_2 X_{Qt-1} + \beta_3 X_{Qt-2} + \beta_3 X_{Qt-3} + \ldots\ldots\ldots + \beta_n X_{Qt-n}$$
$$+ \beta'_1 X_{Dt} + \beta'_2 X_{Dt-1} + \beta'_2 X_{Dt-2} + \ldots\ldots\ldots + \beta'_n X_{Dt-n}$$

$$Q_t = \beta_0 + \beta_1 X_{Qt} + \beta_2 X_{Qt-1} + \beta_3 X_{Qt-2} + \beta_3 X_{Qt-3} + \ldots\ldots\ldots + \beta_n X_{Qt-n}$$

Where,

C_t, F_t, D_t and Q_t are the performance measures of the firm in terms of cost, flexibility, dependability and quality respectively at any time t.

β s are the coefficients corresponding to quality initiatives

β's are the coefficients corresponding to delivery initiatives

β''s are the coefficients corresponding to flexibility initiatives

β'''s are the coefficients corresponding to cost initiatives

X_{Qt} is the quality based improvement measure at time t and similarly for time periods t-1 to t-n.

X_{Dt} is the dependability based improvement measure at time t and similarly for time periods t-1 to t-n.

X_{Ft} is the flexibility based improvement measure at time t and similarly for time periods t-1 to t-n.

X_{Ct} is the cost based improvement measure at time t and similarly for time periods t-1 to t-n.

Hypothesis: we expect the β s, β's, β''s, β'''s of each time period to be significant with a lag for the next time period thus confirming the time dependent characteristic of the Sandcone Model. The hypothesis is illustrated in the table below where the β s, β's, β''s, β'''s should be significant for each time period with a lag.

Table 2:

Time Period	t-1	t-2	....	t-n
quality				x's
dependability			x's	
flexibility		x's	Significant β s	
cost	x's			

Next, a performance plot of each of the companies should be drawn over the study period. The Y-axis of the plot may contain measures of operational excellence or financial excellence and the X-axis will contain the number of years plot. One can argue that a rising graph for a financial performance of a company within the sample shows its performance excellence and hence the initiatives taken by the company can now be investigated. Did it follow the sequence of sandcone model? That should be analysed through regression as suggested above. Or did it bring about strategic changes which were contingent on the then conditions, if so then the sequence of sandcone model may not play an important role in lasting manufacturing improvements. A similar analysis follows for all such companies in the sample after plotting their performance metrics. Similar plots can be drawn between various dimensions like quality vs cost, dependability vs flexibility between the sample of companies and then track each initiative as taken by each company and in what sequence. A questionnaire is presented in appendix C which can be used to question the managers of the firms.

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Insert Questionnaire about here

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The above method for longitudinal studies should help identify the sequence of measures taken by the sample of companies over the 10 years period of time. With such a longitudinal data based study can the sequence of cumulative capability building measures be analysed.

CONCLUSION

This paper makes a significant contribution on two issues which have not been dealt with in other research works namely: The use of longitudinal studies for a path dependent model and a framework for analysing path dependency of capability building measures. The framework suggested for the longitudinal study based approach can be used for future research work for empirically testing the sandcone model. The paper fills the gap in the existing body of knowledge regarding the Sandcone model validity and also gives new directions to the research in the area of operations strategy. Gyampah and Meredith (2007), in their study at Ghana found that the cumulative capability building measures did not follow the sandcone model and

they attributed the reasons to the economy of Ghana. Our India centric study should also reveal such nuances if the model is dependent on other factors like economic conditions. The study will thus prompt further researches in the area of finding the optimum sequences of capability building in developing economies. The present study has its own challenges like how to control the variables external to the firms over the 10 year time period. Future research can be aimed at bettering this model. Managerial implications of this study are plenty. The verification of the sandcone model through the longitudinal studies will provide the much needed support to the optimum sequence of capability building measures that firms should follow. Any refutation of the model would also help further researches in the direction of finding the optimum sequence of capability building. In both ways the study takes us closer to the truth, which Ferdows and DeMeyer started seeking through their study.

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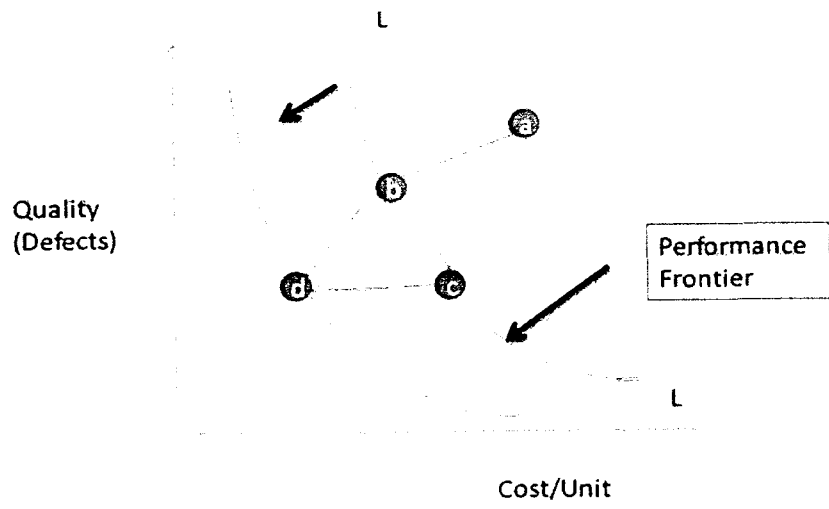
Fig 1

1. Identification of constructs for quality, dependability, flexibility and cost based on study by Rosenzweig and Roth(2004)

2. Identify the Dataset, from manufacturing firms in India determine baseline year

3. Validity and Reliability tests

4. Refinement of terms and development of the instrument

5. Final Instrument development

6. Statistical Tests, Analyse the output of the Measurement

Fig 2

Questionnaire for longitudinal studies

Competitive Capability Measures –*for finding the present market position of the company*

Listed below are the critical success factors for competing in an industry, please indicate how strong you

feel your business unit is for each capability relative to your primary competitors in the same markets.

	Lower		Average		Market Leader
1. Conformance Quality	1	2	3	4	5
2. Reliability of delivery times (on time)	1	2	3	4	5
3. Ability to rapidly change production volumes	1	2	3	4	5
4. Manufacture products at lower internal costs than competition	1	2	3	4	5

Performance Measures – *for plotting the performance of the companies in the study period*

1. Please report the average annual rate of performance in terms of conformance quality during 1998-2008.

2. Please report the average annual rate of performance in terms of reliability of delivery times during 1998-2008.

3. Please report the average annual rate of performance in terms of ability to rapidly change production volumes during 1998-2008.

4. Please report the average annual rate annual rate of performance in terms of ability to manufacture products at lower internal costs than competition during 1998-2008.

Timeline based measures - *this is the most important measure and should help draw a relation between the programs initiated and the performance plot (correlation and regression can be performed further to assert the relationship)*
What were the essential steps you took from 1998-2008? Categorise them in terms of quality measures, cost measures, dependability measures and flexibility measures, along with the time when you adopted the measures:
e.g.

Program	Year of adoption	Is it still continuing?	Why or why not?	QCDF measure?
CAD/CAM	1996	Yes	-	Flexibility measure Also helps maintain quality