Causal Linkages in Soft Systems: Ascertaining Causal Linkages among the Factors of Work Climate and the Measures of Effectiveness of Research Units in an R&D Organization

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ABSTRACT: *The systems approach is a means of studying the properties of things in relation, not just to their components, but also to the ways in which the components interact, both with each other and with their environment. Within this approach, the task of ascertaining causal linkages existing among the variables in soft systems (as against hard systems) is more complex as these are often messy and the objectives are hard to define. The study reported here has investigated into the causal relationships among the measures of effectiveness of research units of different laboratories under CSIR, India and the factors affecting the work climate of these units using structural equation modelling methodology and LISREL 7.16 program. Two causal models linking these dimensions have been developed.*

Keywords: Soft systems, causality, reliability, structural equation models, LISREL, parameters, model fit.

INTRODUCTION

The field of systems research is still a lively subject of debate (Espejo, 1994; Ackoff and Gharajedaghi, 1996; LaPointe, 1998). From the initial thrust on hard systems approach, the emergence of soft systems management could be viewed as the failure of system engineered concepts to be applied to the resolution of 'messy' people based organizational problems (Bolton & Gold, 1994). The focus has thus changed to the soft system, the human activity and relationships within the hard system (Bentlay, 1992; Mason (1997). The importance of soft modelling methodologies had been recognized way back by van Gigch (1974), 'The outputs of 'hard' systems are for the most part tangible and 'quantity-like' as opposed to those of soft systems which may be characterized by a greater proportion of 'quality-like' outputs. For this reason it is expected that the outputs of 'soft' systems will be measurable along weaker scales of measurement than the outputs of 'hard' systems….special methods will have to be devised to cope with that limitation' (p. 169). Various researchers have attempted to apply different soft OR methods in managerial problem solving and strategy formulation exercises (Brocklesby and Cummings, 1995; Ormerod, 1998; Liao, 1998). The systems approach is thus a means of studying the properties of things in relation, not just to their components, but also to the ways in which the components interact, both with each other and with their environment (Holling, 1995; Nicholas, 1990; Lane and Jackson, 1995). Causal modelling adds precision to one's theory, makes it explicit, allows for better representation of the complex inter-relationships, and formalizes the scientific inquiry.

THE SUBJECT OF CAUSALITY

The authors (Roy and Mohapatra, 1994) have earlier attempted to model the work climate of a research and development (R&D) organization using the system dynamics framework. The causal relationships in this particular system dynamics model had been largely derived from correlations, regression analysis, cluster analysis and multiple classification analysis. The problem, however, is that in none of the methods of analysis mentioned above, causality can be inferred or verified (Mass and Senge, 1978; Lane, 1995). According to Bollen (1989), the definition of cause has three components: isolation, association and the direction of influence. Goldenberg (1998) has argued that there are four basic criteria for the establishment of a causal relationship - association, time order, non-spuriousness and rationale. Causality is a major factor in the events that form organizational behaviour (Humphreys, 1989).

Many concepts in sociology are difficult or impossible to objectively measure. This limitation forces a reliance on subjective measures that typically contain both systematic and random measurement errors. Bollen and Paxton (1998) have demonstrated the feasibility of investigating biases in subjective measures under a broad range of research designs. The present study ascertains the causal linkages among the measures of effectiveness and the factors of work climate of research units in R&D laboratories under the Council of Scientific and Industrial Research (CSIR), India, keeping the above considerations into account.

DEVELOPING THE CAUSAL MODELS - METHODOLOGY

LISREL technique (Joreskog, 1973, 1978; Bollen, 1989) has been adopted as the primary methodology. The model incorporates unobserved (latent) variables, the relation between these and observed variables and an allowance for errors of measurement in the independent and dependent latent variables, and a causal model linking the latent variables together. It consists of two components - the measurement model and the structural model. LISREL 7.16 program (Joreskog and Sorbom, 1989) have been used in the study reported in the present paper.

After a two-stage random sampling process involving 602 research units in 32 laboratories of CSIR, India, usable data were obtained from 236 research units. The data were used to develop two structural equation models incorporating latent variables conceptualizing various dimensions of work climate and measures of effectiveness of the research units. In these models, four measures of effectiveness of research units have been used, viz., R&D effectiveness, recognition, user-oriented effectiveness and administrative effectiveness, which were developed earlier in the form of a measurement model (Roy, Nagpaul and Mohapatra, 1998).

Internal consistency of the indices for all the latent constructs were assessed using Cronbach Alpha coefficient (Cronbach, 1951) which ranges from 0, no reliability to 1, perfect reliability (Lord and Novick, 1968), before the structural models were developed using these latent constructs. From the initial list of latent variables, only those variables were taken up for further studies whose Cronbach Alpha coefficients were more than 0.5. The values of Cronbach Alpha coefficients for each of the latent variables along with their respective indicators (within brackets) are given as follows: conflict (0.7499), technical services effectiveness (0.7331), applied research thrust (0.5568), research planning quality (0.6245), communication (0.5939), supervisor contact effectiveness (0.5518), administrative constraints (0.5401), leadership quality (0.6020), research orientation (0.5311), innovative ethos (0.6490), R&D effectiveness (0.5010), user-oriented effectiveness (0.7020), administrative effectiveness (0.5019), and recognition (0.6974).

The first structural model involves the following exogenous variables – applied research thrust (ART) and technical services effectiveness (TEC) and the following endogenous variables – innovative ethos (ETH), administrative constraints (ADC), communication (COM), research orientation (RES), user-oriented effectiveness (USE) and administrative effectiveness (AEF). Out of a total of 12 proposed causal parameters in the hypothesized model linking these variables, 6 were found to be significant which have been displayed in Figure 1. In the figure, the t-values are shown against each causal link and the corresponding parameter estimates are given within brackets alongside. Any t-value greater than 2.00 could be regarded as indication of parameter estimates significantly different from zero (significant at 0.05 probability level). Table 1 shows the various statistic indicating the fit of the structural model 1 to the data. Joreskog and Sorbom (1984) have recommended three indices to judge the fit of the path analytic model to the data. These are χ^2 (chi-square), goodness-of-fit index (GFI) and root mean square residual (RMSR). Chi-square was used as a measure of the fit of the hypothesized model to the actual covariance data; the lower the χ^2 value, the better the fit. A rule of thumb for models with high degrees of freedom (df) is that a well fitting model should have a χ^2/ df ratio of 2 or lower (Rahim and Psenicka, 1996). The GFI measures the relative amount of variance and covariance accounted for by the model. The value of GFI ranges from 0 (poor fit) to 1 (perfect fit). GFI is relatively stable in sample size smaller than 250 (Hu and Bentler, 1995). The RMSR is a measure of the average variance unaccounted by the model. The RMSR for our model is the average residual correlation as the input matrix to our model was a correlation matrix. Ideally, χ^2 should be small and insignificant, GFI between 0.90 and 1.00, and RMSR, small relative to the average variances and covariances in the input matrix. The chi-square statistic for this model is 34.42 with 13 degrees of freedom. (p=0.001). The χ^2 /df ratio is therefore found to be not lower than 2. However, the chi-square statistic is not a reliable test of model fit. Hypothesis testing with the chi-square test is affected by the size of the sample being analyzed (Long, 1983). In very large samples, almost any model with positive degrees of freedom is likely to be rejected. It would seem to provide a statistically unacceptable fit. This is true even when the rejected model is what Bentler and Bonnet (!980) call 'minimally false'. In small samples, the χ^2 test lacks power as it is too forgiving of important miss-specifications in the model. The GFI for this model is 0.961 indicating acceptable fit of the model. The RMSR value for this model is 0.059 and this value is nearly equal to its threshold value (≤ 0.05). The table also shows the squared multiple correlation (R^2) and coefficient of determination for the structural equations of the model. The squared multiple correlations are the measures of variances explained by the model for the endogenous concept variables, whereas the coefficient of determination is the percent of variance explained by the structural equations of the model. Although the model fits the data well, there are variances in the η variables not explained by the model as illustrated by the multiple correlations for the η variables. The total coefficient of determination (percent variance explained by the six structural equations) is 0.597. The second structural model involves the following exogenous variables – leadership quality (LSQ) and supervisor contact effectiveness (SCE) and the following endogenous variables – innovative ethos (ETH), conflict (CON), communication (COM), research planning quality (RPQ), R&D effectiveness (REF), and recognition (REC). Out of a total of 16 proposed causal parameters in the hypothesized model linking these variables, 9 were found to be significant which have been displayed in Figure 2. Table 2 shows the various statistic indicating the fit of the structural model 2 to the data. The chi-square statistic is 30.15 with 12 degrees of freedom. (p=0.003). The χ^2 /df ratio is again found to be not lower than 2. However, the chi-square statistic is not a reliable test of model fit as has been discussed earlier. The GFI for this model is 0.965 indicating acceptable fit of the model. The RMSR for our model is the average residual correlation as correlation matrix was used for the analysis. The RMSR value for this model is 0.069, nearly equal to its threshold value (≤ 0.05). The table also shows the squared multiple correlation (R^2) and coefficient of determination for the structural equations of the model. Here again, although the model fits the data well, there are variances in the η variables not explained by the model as illustrated by the multiple correlations for the η variables. Clearly, there are other variables, not considered in the model, the inclusion of which might improve these parameters and/or there are other causal linkages needing consideration. The total coefficient of determination is 0.333.

Table 1:
Goodness-of-Fit Indices for
Structural Model 1

Chi-Square with 13 Degrees of Freedom (p=0.001)	34.42
Goodness-of-Fit Index (GFI)	0.961
Root Mean Square Residual	0.059
Squared Multiple Correlations for	
Innovative Ethos	0.666
Administrative Constraints	0.065
Communication	0.887
Research Orientation	0.628
User-Oriented Effectiveness	0.534
Administrative Effectiveness	0.454
Total Coefficient of Determination of the Six Structural Equations	0.597

Table 2:
Goodness-of-Fit Indices for
Structural Model 2

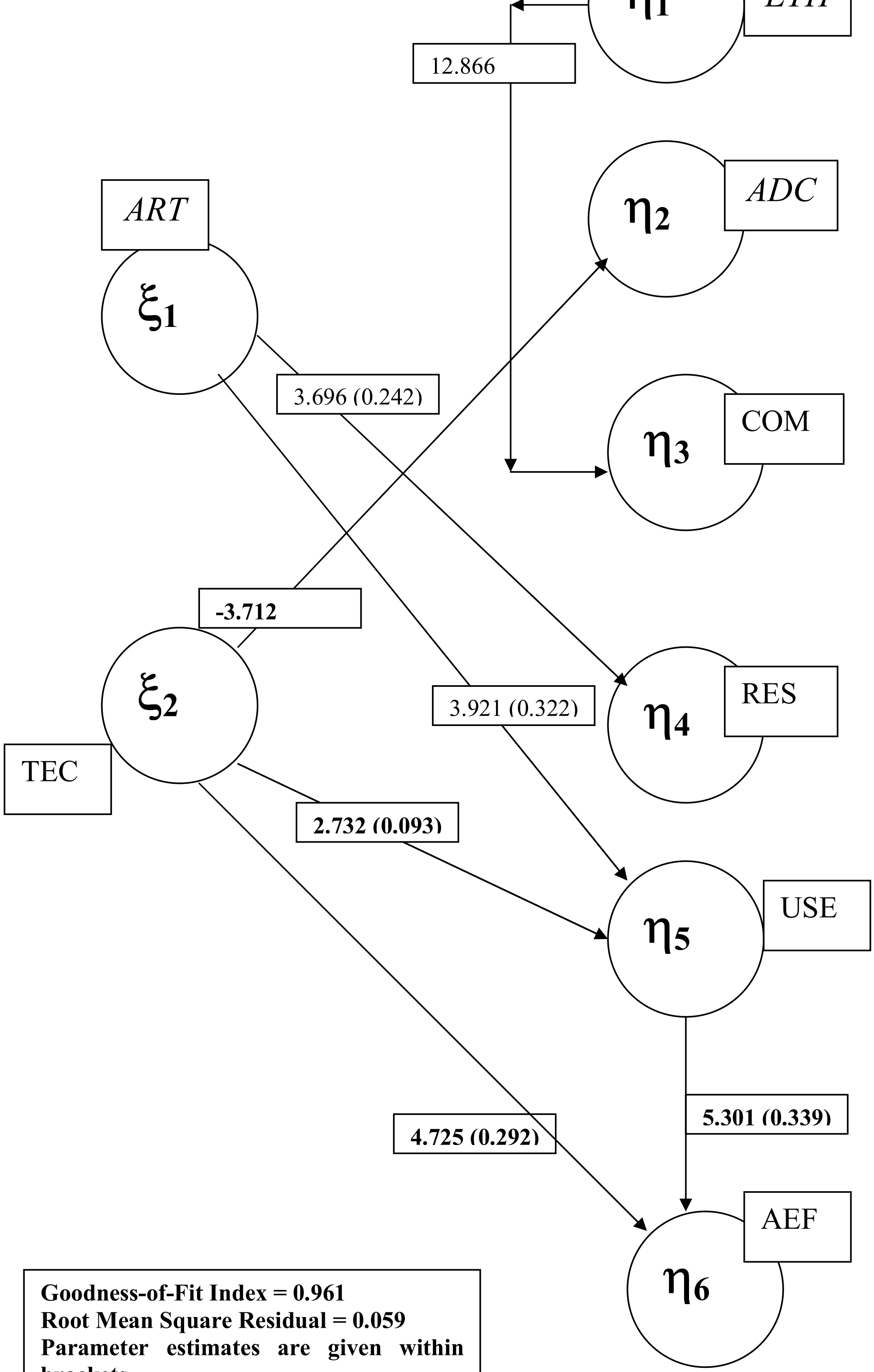
Chi-Square with 13 Degrees of Freedom (p=0.003)	30.15
Goodness-of-Fit Index (GFI)	0.965
Root Mean Square Residual	0.069
Squared Multiple Correlations for	
Innovative Ethos	0.141
Conflict	0.013
Communication	0.531
Research Planning Quality	0.550
R&D Effectiveness	0.105
Recognition	0.385
Total Coefficient of Determination of the Six Structural Equations	0.333

REFERENCES

Ackoff, R.S., Gharajedaghi, J., Reflections on Systems and their Models, *Systems Research*, 13(1), 1996, 13-23.

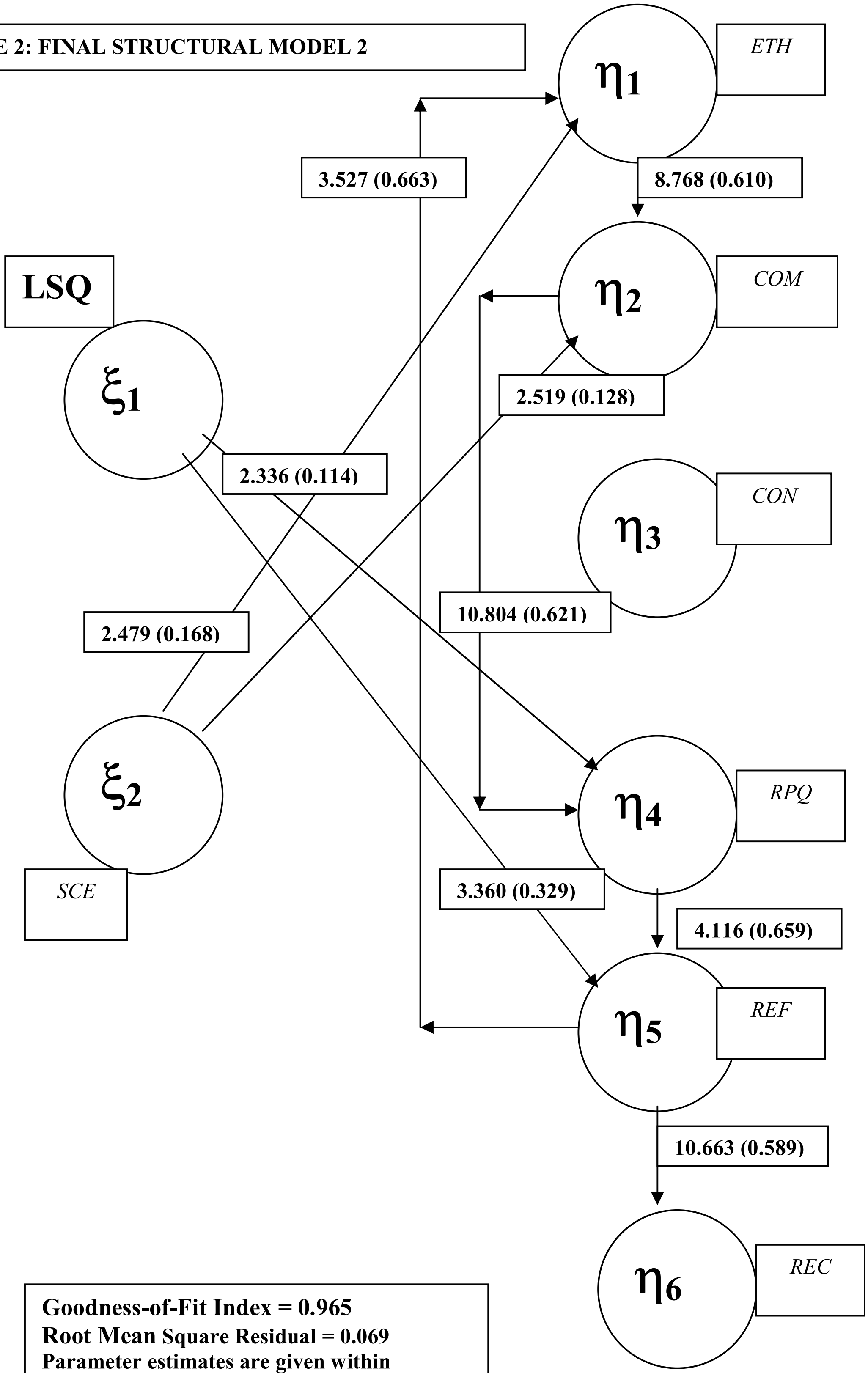
Bentler, P.M., D.G. Bonnet, Significance Tests and Goodness of Fit in the Analysis of Covariance Structures, *Psychological Bulletin*, 88, 1980, 588-606.
Bentley, T., Soft Systems Methodology, *Management Accounting,* July-August, 1992.
Bollen K.A., *Structural Equation with Latent Variables*, John Wiley and Sons, New York, 1989.
Bolton, R., Gold, J., Career Management: Matching the Needs of Individuals with the Needs of the Organization, *Personnel Review*, 23(1), 1994, 6-24.
Brocklesby, J., Cummings, S., Combining Hard, Soft and Critical Methodologies in Systems Research: The Cultural Constraints, *Systems Research*, 12(3), 1995, 239-245.
Cronbach, L.J., Coefficient Alpha and Internal Structure of Tests, *Psychometrica*, 16(3), 1951, pp. 297-334.
Espejo, R., What is Systemic Thinking?, *System Dynamics Review*, 10(203), 1994, 199-212.
Goldenberg, S., Rediscovering and Confronting Critical Ambiguities in the Determination of Causality, *Quality & Quantity,* 32, 1998, 181-200.
Holling, C.S., What Barriers? What Bridges?, in *Barriers and Bridges to the Renewal of Ecosystems and Institutions*, Gunderson, L.H., Holling, C.S. and Light, S.S. (eds.), Columbia University Press, NY, 1995.
Hu, L. and Bentler, P.M., Evaluating Model Fit, in Hoyle, R.H. (ed.), *Structural Equation Modelling: Concepts, Issues and Applications*, Sage, Thousand Oaks, CA, 1995.
Humphreys, P., *The Chances of Explanation*, Princeton University Press, Princeton, NJ, 1989.
Joreskog, K., Sorbom, D., *LISREL 7.16: Analysis of Linear Structured Relationship by Maximum Likelihood and Least Squares Method*, International Educational Services, Chicago, 1989.
Joreskog, K.G., A General Method for Estimating a Linear Structural Equation System, in, *Structural Equation Models in the Social Sciences*, Goldberger, A.S., Duncan, O.D. (eds.), Seminar, New York, 1973, 85-112.
Joreskog, K.G., Sorbom, D., *LISREL VI User's Guide*, Scientific Software, Mooresville, IN, 1984.
Joreskog, K.G., Structural Analysis of Covariance and Correlation Matrices, *Psychometrica*, 43(4), 1978, 443-477.
Lane, D.C. , Jackson, M.C., Only Connect! An Annotated Bibliography Reflecting the Breadth and Diversity of Systems Thinking, *Systems Research*, 12, 1995, 217-228.
Lane, D.C., The Folding Star: A Comparative Reframing and Extension of Validity Concepts in System Dynamics, in Simada, T., Saeed, K. (eds*.), Proceedings of 1995 International System Dynamics Conference*, July. 30 – Aug. 4, Cambridge, MA, System Dynamics Society, 1995, 111-130.
LaPointe, G., Human Nature, Humanistic Social Systems, and Design, *Systems Research and Behavioral Science*, 15, 1998, 193-208.
Liao, Z., A Systematic Integration Model to Support Complex Decision-Making in a Dynamic Environment, *Systems Research*, 15, 33-45.
Long, J.S., *Covariance Structure Models: An Introduction to LISREL*, Sage, Beverly Hills, California, 1983.
Lord, F.M., Novick, M.R., *Statistical Theories of Mental Test Scores*, Addison Wesley, Reading, MA, 1968.
Mason, G.L., A Conceptual Basis for Organizational Modelling, *Systems Research and Behavioral Science*, 14, 1997, 331-345.
Mass, N.J., Senge, P.M., Alternative Tests for the Selection of Model Variables, *IEEE Transactions on Systems, Man and Cybernetics*, June (8/6), 1978, 250-259.
Nicholas, J.M., Managing Business and Engineering Projects, Prentice-Hall, Englewood Cliffs, NJ, 1990.
Ormerod, R.J., Putting Soft OR Methods to Work: Information Systems Strategy Development at Palabora, *Omega: International Journal of Management Science*, 26(1), 1998, 75-98.
Rahim, M.A., Psenicka, C., A Structural Equation Model of Stress, Locus of Control, Social Support, Psychiatric Symptoms, and Propensity to Leave a Job, *The Journal of Social Psychology,* 136(1), 1996, 69-84.
Rahim, M.A., Psenicka, C., A Structural Equation Model of Stress, Locus of Control, Social Support, Psychiatric Symptoms, and Propensity to Leave a Job, *The Journal of Social Psychology*, 136(1), 1996, 69-84.
Roy, Santanu and Mohapatra, P.K.J., Study of Work Climate in R&D Organizations: A System Dynamics Approach, in *System Dynamics: Exploring the Boundaries*, 1994 International System Dynamics Conference, University of Stirling, Scotland, UK, Vol. Production and Operations Management, System Dynamics Society, 1994, 61-70.
Roy, Santanu, Nagpaul, P.S., Mohapatra, P.K.J., Measuring R&D Productivity: Model Development and Causality, in *Proceedings of International Conference on System Dynamics (ICSD – 98)*, Dec. 15-18, 1998, Mahanty, B. and Mohapatra, P.K.J. (eds.), Department of Industrial Engineering and Management, Indian Institute of Technology, Kharagpur, and System Dynamics Society of India, 1998, 430-444.
van Gigch, J.P., *Applied General Systems Theory*, Harper and Row, New York, 1974.

FIGURE 1: FINAL STRUCTURAL MODEL 1



Goodness-of-Fit Index = 0.961
Root Mean Square Residual = 0.059
Parameter estimates are given within brackets
Only significant t-values are shown

FIGURE 2: FINAL STRUCTURAL MODEL 2



Goodness-of-Fit Index = 0.965
Root Mean Square Residual = 0.069
Parameter estimates are given within brackets
Only significant t-values are shown