Modeling Engineering Competence Pool: System Dynamics Based Implications for KM & HRM Integration

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Abstract

This paper focuses on the application of system dynamics in the integration of knowledge management (KM) and human resource management (HRM) with specific reference to the determination of the optimum setting of time-based policy parameters. The integration of KM and HRM is w.r.t. the engineering competence pool development and deployment. The feedback, as well as feed-forward loops, were used in the development of the control loops, which govern the simulation carried out in two distinct stages. In both the stages, the influence of the governing time-based policy parameters has been studied to investigate the critical parameters, which significantly influence the effectiveness of the system. The simulation results envisage the effect of the policy parameters, based on which implications are drawn for better policy evaluation and control. Even though the study has a national context, the procedure adopted in this research has the potential to be extended to the global level.

Key Words: System dynamics, Competence pool model, Cybernetics, Systemic thinking, Learning organization, Knowledge management, Simulation, Social system.

Abbreviations and Notations:

AECPL = Actual Engineers' Competence Pool Level.
ALCA = Actual Level of Competence Absorbed.
CPG = Competence Gap.
CTCRATE = Competence Training Completion Rate.
CTRATE = Competence Training Rate.
DECPL = Desired Engineers' Competence Pool Level.
FGCFR = Forecast Graduate Competence Fail Rate.
FSKFR = Forecast Skill Fail Rate
GECOPM = Graduate Engineers' Competence Pool Model.
GET = Graduate Engineering Training
HRM = Human Resource Management.
KM = Knowledge Management.
PECOPM = Practicing Engineers' Competence Pool Model.
PGCFR = Present Graduate Competence Fail Rate.
PSKFR = Present Skill Fail Rate
RCRATE = Recruitment Completion Rate
RRATE = Recruitment Rate
SKG = Skill Gap
T_a = Average time to determine the forecast competence loss rate.
TCRATE = Training Completion Rate
T_{dt} = Competence Training Delay Time.
T_r = Time over which the competence gap is to be recovered.
TRATE = Training Rate
T_{rd} = T_{dr} = Recruitment Delay Time.
T_s = Skill Gap Recovery Rate
T_{sl} = Skill Loss Rate Averaging Time.
T_{td} = Training Delay Time

Literature Review

The era of knowledge and technology management has already begun and technical manpower development is gaining importance more than ever before, both on the national and international front. Today, competence development and deployment of technical manpower is in the forefront of the national agendas of several nations as it contributes to the economy of the country. System Dynamics has a very significant role to play in manpower planning as it provides a means to model the dynamic system and envisages the influence of policy parameters. Competence development in engineering includes both ‘tacit’ and ‘explicit’ knowledge (Nonaka & Takeuchi 1995, 60), which constitute the two types of knowledge to be managed in knowledge intensive organizations.

Defining KM is not only problematic but also varies from person to person based on the context and use (Davenport and Prusak 1998, 5; Neef 1999, 72-78; Bhatt 2001, 68-75; Raub & Rulling 2001, 113-130). Turban & Aronson (2001, 439-445), describe KM as a process that helps organizations identify, select, organize, disseminate, and transfer important information and expertise that are part of the organizational memory that typically resides within the organization in an unstructured manner. We select this definition, as it is the most appropriate in the context of engineering competence development.

The HRM mainly involves planning, which involves five stages viz., analysis of the system, deciding the time horizon of the plan, forecasting the demand for and supply of manpower, reconciliation, and preparation of action plans (Tripathi 2002, 81). So, the study of the system forms the very first phase of the HRM. This issue is of national significance as the economy of the country is tied to the database of the knowledge workers, in today’s knowledge-based economy.

System Dynamics (SD) is basically built upon the traditional management of social system, cybernetics and computer simulation (Sushil 1993, 29). SD is based on the philosophy that the behavior of a system is principally caused by its structure, based on policies & traditions. Further, the structure of an organization can be best represented in terms of underlying flows of various resources cutting across the functional departments tracing across various feedback loops, delays and amplifications in the system. The SD model typically consists of ‘causal loop’ and ‘flow diagram’. The causal loop depicts causal hypothesis during model development, so as to make the presentation of the structure in an aggregate form, whereas, flow diagrams represent the detailed flow structure of the system in terms of the fine policy structures so as to facilitate the development of the mathematical model for simulation (Coyle 1977, 413; Morecroft 1982, 20-29). In this paper we use causal loop diagrams, flow diagrams and control loops to solve the equations and simulate results.

Objectives of the study

The KM is concerned with the engineering competence development and HRM deals with the engineering competence deployment. The overall goal of this research is to apply system dynamics to the integration of KM & HRM so as to improve upon the policy imperatives. Specifically, the following objectives are formulated to achieve the overall goal of this study:

- Identifying and relating variables within the system using the principles of cybernetics.
- Developing causal loop diagram for KM & HRM integration.

- Constructing the flow diagrams.
- Formulating the governing equations.
- Designing the control loop for KM & HRM integration.
- Simulating the model for predefined values of policy parameters.

The simulation results thus obtained would enable the generation of performance indices tables, based on which, the effect of policy parameters on KM & HRM integration is envisaged. The results would give the conditions for optimum performance of KM & HRM initiatives, thus contributing to the policy scenario building and its improvement on a continuous basis.

Research Methodology

This research involves areas such as knowledge management, systemic thinking, cybernetics, system dynamics, and learning organization. Knowledge management, in the context of this paper, basically involves the creation, validation, storage, dissemination and utilization of competence developed in the engineering institutes (Natarajan and Sandhya 2000, 27). Systemic thinking is employed in developing a system by integrating the sub-systems of engineering education and industry (Senge 1994, 424). Cybernetics principles were used in establishing ***causalism*** (Negoita 1992, 40) based on which the flow diagrams (Mass 1986, 76-80) were developed. The flow diagrams provided the basis for the formulation of governing equations of the models. The control loop diagrams representing these equations were then developed to conduct simulations (Law and Kelton 1991, 306). The engineering competence pool models thus developed is subjected to simulation and validation through the principles of system dynamics. The output results of simulation and its interpretation enter into the knowledge repository of the system model, thus promoting the concept of learning organization.

The research methodology goes in accordance with the principles of cybernetics as proposed by Norbert Wiener (1948, 11-12) & Ross Ashby (1957, 53) and System Dynamics methodology proposed by Jay Forrester (1994, 245-256), which has been used by a group of researchers (Coyle 1977, 413-422; Towill 1982, 674; Cheema et al. 1989, 101-105; Morecroft 1999, 315-336; Winch 1999, 354-361; Hafeez & Abdelmeguid 2003, 153-164 and Rodrigues & Morvin 2004) in different situations. The Inventory and Order Based Production Control Structure (IOBPCS) by Towill (1982, 671-687) and Skill Pool Model (SKPM) developed by Hafeez & Abdelmeguid (2003, 153-164) provided the basis for the development of GECOPM & PECOPM of this paper. The key steps in the methodology of this paper involved: Problem identification, Cybernetics, Model formulation, Simulation & validation and Policy analysis & improvement.

To start with, the situation analysis (Checkland and Holwell 1998, 9-21) was performed, which included problem identification i.e. KM & HRM dynamics in engineering education and the study of the number of engineers produced in the country per year and their absorption rate. "An editorial in *The Times of India*, 16 August 2004 stated that 250,000 engineers pass each year out of whom about one-fourth are unemployed". This statistics was used to initialize the Desired Engineers' Competence Pool Level (DECPL) in the models. The simulation was carried out in two stages. These two stages were necessary as there are two distinct systems viz. engineering institutes and industries, which involve the integration of KM and HRM individually.

In stage-1 (Graduate Engineers' Competence Pool Model (GECOPM)) of modeling, the successful completion of graduation and their absorption was considered. Under the ideal situation, Actual Engineers' Competence Pool Level (AECPL) would match the Desired Engineers' Competence Pool Level (DECPL). But this may not be practically true because competence loss due to failure, or drop out, or any other reason is unavoidable. So, to maintain a constant level of AECPL, forecasting of the rate of competence loss will be necessary. This will provide information regarding the additional engineering graduates to be admitted in the subsequent years so as to meet the desired level. Hence, the Competence gap recovery time (T_r) has its influence on AECPL, Competence Training Completion Rate (CTCRATE), and Actual Level of Competence Absorbed (ALCA). Similarly, the other time-based policy parameters viz. Average time to determine the Forecast competence loss rate (T_a), Competence training delay time (T_{dt}), and Recruitment delay time (T_{dr}) have influence on AECPL, CTCRATE and ALCA.

The term 'competence' used in the context of stage 1 includes- knowledge, skill and attitudes of the engineers/future engineers that would enable them to be employed in the global market, join higher studies, or become entrepreneurs. 'Competence loss' refers to the failure of the students to be employable, pursue higher studies, or become entrepreneurs.

The stage-2 model (Practicing Engineers' Competence Pool Model (PECOPM)) considers industrial/apprenticeship training of the engineers. This refers to the industry specific competence training that engineers need to undergo so as to fit into industrial requirements. Again, under ideal conditions, all the students who join engineering should successfully complete their graduation, get absorbed in the market, as well as successfully pass the industrial training. But in practice, there could be a competence loss at any of these three phases. Hence, the Competence gap recovery time (T_r) in this stage has its influence on Training completion rate (TCRATE), Actual level of competence absorbed (ALCA) and Recruitment completion rate (RCRATE). In addition, Competence training delay time (T_{dt}), Average time to determine the forecast competence loss rate (T_a), Skill gap recovery rate (T_s), Industrial training delay time (T_{td}) and Skill loss rate averaging time (T_{sl}) also have their influence on TCRATE, ALCA and RCRATE. However, only the simulation results of TCRATE and ALCA have been shown in this paper, as the influence of policy parameters on RCRATE was comparatively low.

The term 'competence' used in the context of stage 2 includes- knowledge, skill and attitudes acquired in engineering plus the skills gained during the training/apprenticeship in the industry that would enable them to be employed in the local/global market or become entrepreneurs.

To represent the above two stages in the form of a system dynamics model, causal loop diagrams were developed for the two stages (Fig. 1a & 1b). This considered the parameters that have significant influence on knowledge, skill and attitude development that provides the required level of competency to the engineers. A sustainable development of engineering competence has been the focus in the development of causal relations, as engineers who fail to develop the required level of competency to be absorbed in the market, add to 'competence loss', which in turn is detrimental to the growth of the country. Various influences are represented in the form of feed-forward and feedback loops. A computer simulation of this model is possible but is of limited use as the change in individual parameters (e.g. recruiting rate) cannot be isolated easily (Hafeez & Abdelmeguid 2003, 155).

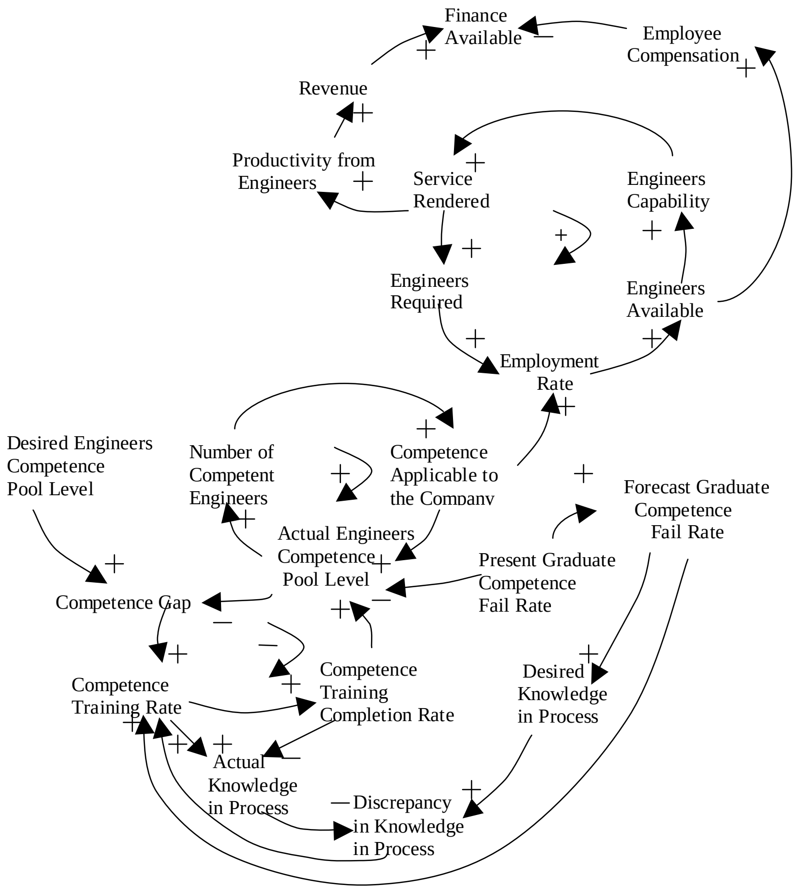

Fig 1a: Causal Loop Diagram of GECOPM (Stage 1)

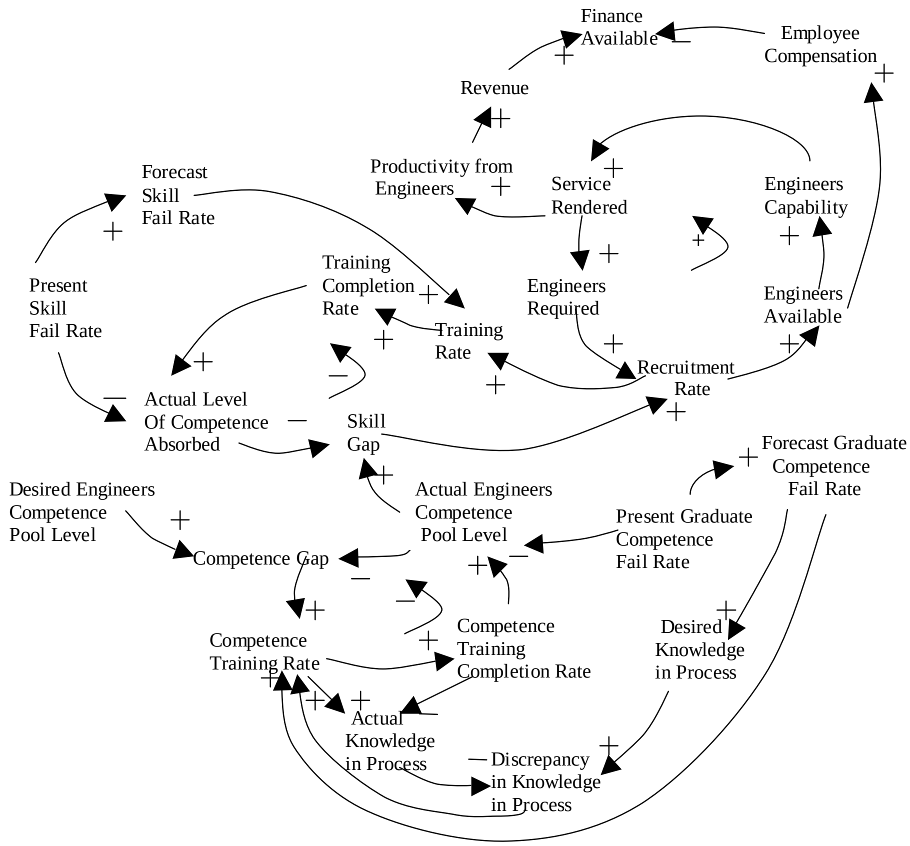

Figure 1b: Causal Loop Diagram of PECOPM (Stage 2)

The next step was to develop Flow Diagrams (Fig. 2a & 2b). This mainly illustrates the feedback (based on competence gap) and feed-forward control (based on forecast competence loss rate). Time-based policy parameters have been considered to analyze the dynamic response. The governing equations giving discrete-time feed-forward and feedback differences are then formulated, which provide basis for the development of control loops. The control loop diagram with the sample output of the GECOPM (delay: 6 months) and PECOPM (delay: 6 months education sector, 3 months industrial sector) is shown in Fig. 3a and 3b for the two stages under consideration.

The main purpose of the entire system is to match the DECPL with the ALCA. To achieve the DECPL, a simple appropriate policy is proportional control, where information containing the magnitude of the level is fed back to control the competence-training rate (Hafeez & Abdelmeguid 2003, 162). The competence-training rate may be calculated by dividing the discrepancy between the desired and actual value of the level by a time factor, which represents the average delay in performing the training rate.

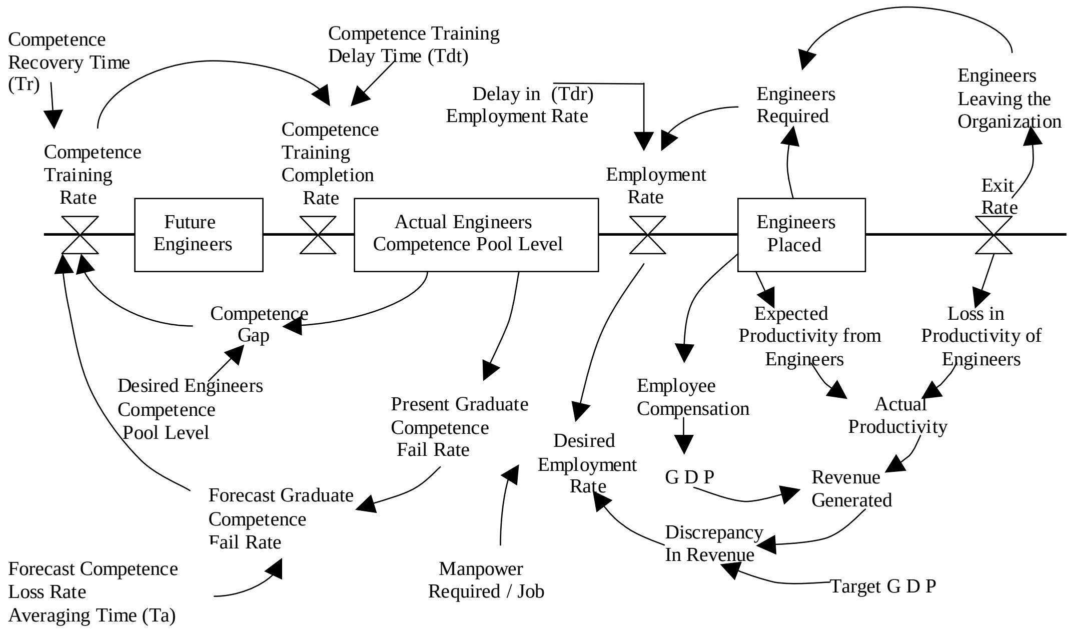

Figure 2a: Flow Diagram of GECOPM (Stage 1)

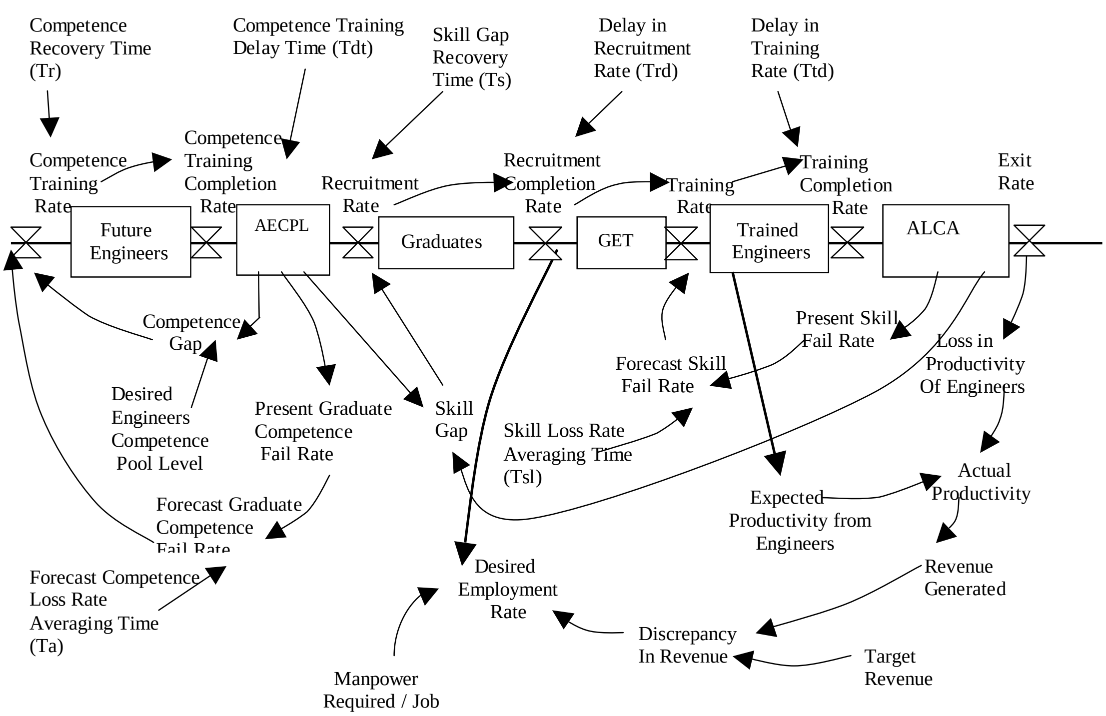

Figure 2b: Flow Diagram of PECOPM (Stage 2)

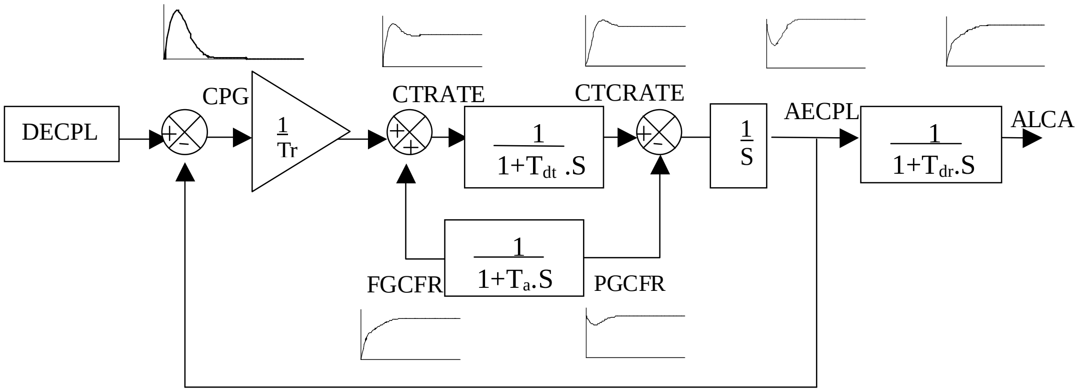

Figure 3a: Control Loop with Sample Output of GECOPM (Stage 1)

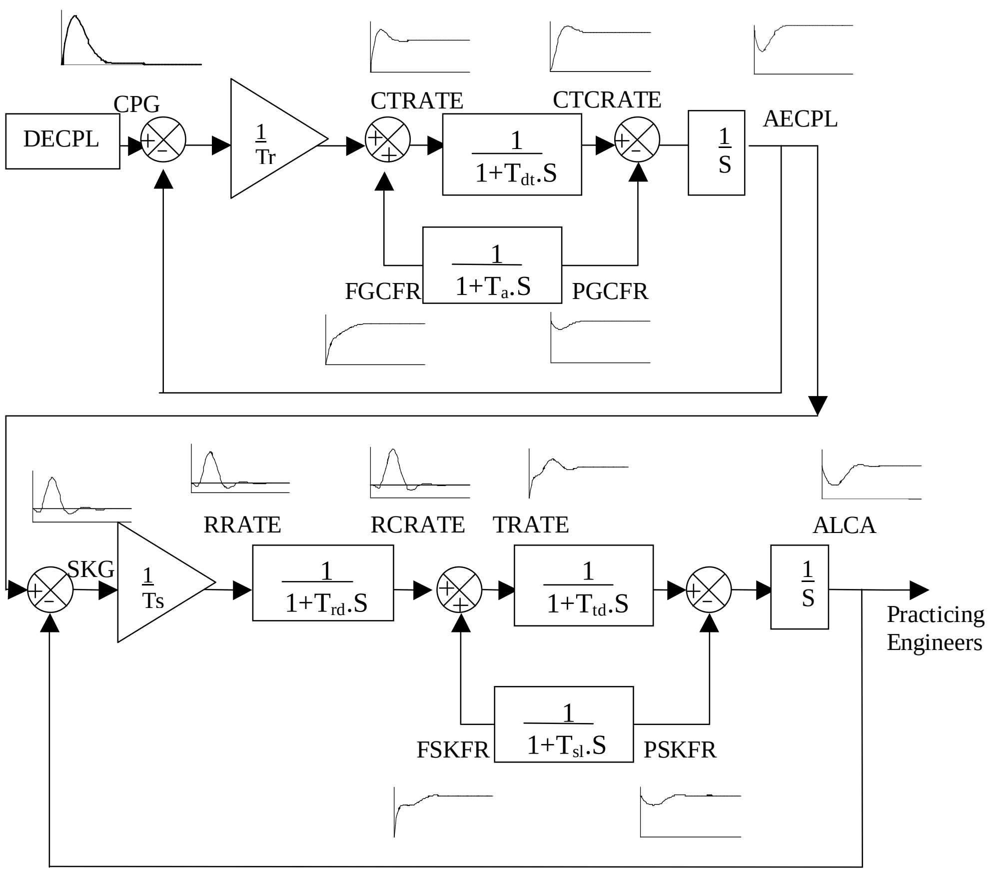

Figure 3b: Control Loop with Sample Output of PECOPM (Stage 2)

Dynamic Analysis

The main purpose of dynamic analysis is to study the effect of time-based policy parameters T_a, T_r, T_{dt}, & T_{dr} (Stage 1) and T_r, T_{dt}, T_a, T_s, T_{td} & T_{sl} (Stage 2) on GECOPM and PECOPM. The influence of these parameters on the performance indices: CTCRATE, AECPL, TCRATE and ALCA will provide useful input for policy makers. The parameter setting for dynamic analysis of the two stages is as follows.

Stage 1: Graduate engineers' competence pool model

- DECPL = 250,000 units.
- The delay time in training is taken to be 6 months to enable them to get the required competence level through re-training.
- The drop out is about 5% of engineers.

Stage 2: Practicing engineers' competence pool model

The AECPL of stage-1 is the input to the stage-2. This analysis considers the dynamics in training and retraining of the graduates before being absorbed in the market.

- The retraining time is 3 months.
- The skill loss is assumed to be 5%.

The MATLAB Version 6.5 software was used for producing simulation results. Based on the study results the Performance Indices Tables were developed to provide information on the optimum setting of policy parameters. Inferences were also drawn so as to decide the most critical policy parameters, which have significant influence on the two models.

After simulation the model was validated so as to determine if the model's output behavior has sufficient accuracy for the model's intended purpose over the domain of the model's intended applicability. This paper uses the validation procedures proposed by Sterman (2000, 845), Barlas (1996, 183-210), and Forrester & Senge (1980, 209-228). The tests used for validation of the GECOPM and PECOPM are: Boundary-Adequacy Test, Structure Assessment Test, Dimensional Consistency Test, Parameter Assessment Test, Extreme Condition Test, Behavior Reproduction Test, Behavior Anomaly Test, Family-Member Test, Surprise Behavior Test, and Parameter Sensitivity Analysis Test. These tests check the validity, credibility and generality (Solberg 1992, 215-223) of the model. However, the validity of the model would be proved through the application of the optimum policy parameter settings suggested in this research in real-life situations during the implementation stage.

Results & Findings

The performance indices tables are given in Appendices Ia & Ib. The detailed discussions on the simulation results for the two distinct stages are as follows.

Stage 1:

1. Influence of Competence Gap Recovery Time (T_r)

Simulation was conducted with $T_{dt} = T_a = T_{dr} = 6$ months (Maximum period for competency recovery) and T_r was varied from 0 to 50 months.

Competence Training Completion Rate (CTCRATE)

The simulation result shown in figure 4a, depicts that smaller values of T_r will take less time for the CTCRATE to rise to its peak value. But at the same time, this may result in unwanted oscillations, thereby increasing the settling time, which is clearly a case of bad system design as per the principles of control theory. The system takes a very long time (35 months) to settle down. However, the graph also depicts clearly that Increasing T_r; increases the time for rise, decreases the peak value and decreases the CTCRATE gradually.

Actual Engineers' Competence Pool Level (AECPL)
Figure 4b illustrates the influence of T_r on the AECPL. In the worst case, the system would take 80 months to recover the competence loss if T_r is more than about 30 months. On the other hand, a small value of T_r would allow a quick competency recovery (about 5 months). But if T_r is fixed to be very small, unwanted oscillation in the competence skill pool may result for a long period (about 35 months). Hence, we can conclude that T_r has a higher influence on the system than the other policy parameters. Moreover, according to the principles of control theory this constitutes a bad system, as the number of oscillations are supposed to be minimum.

Actual Level of Competence Absorbed (ALCA)
Figure 4c shows the response of the ALCA for a range of time values over which the competence gap is to be recovered (T_r). Higher values of T_r indicate that the ALCA takes more time to rise. Also, the level of graduates being absorbed becomes less compared to lower values of T_r. The system takes 60 months to settle i.e. the system is able to recover from the shortages only after a duration of 60 months for higher value of T_r . However, a smooth rise in competence level absorption is observed with almost no oscillations.

2. Influence of Average time to determine the Forecast Competence Loss Rate (T_a)
Simulation was conducted with $T_{dt} = T_r = T_{dr} = 6$ months (Maximum period for competency recovery) and T_a was varied from 0 to 50 months.

Competence Training Completion Rate (CTCRATE)
The simulation result shown in figure 5a depicts that for smaller values of T_a, CTCRATE will take less time to rise to its peak value. The system takes 55 months to settle down. However, the graph also depicts clearly that Increasing T_a; increases the time for rise, decreases the peak value and decreases the CTCRATE gradually.

Actual Engineers' Competence Pool Level (AECPL)
Figure 5b shows that as T_a is gradually increased, competence pool drop also increases, indicating that the system is unable to recover from the competence shortages over a period of time. The competence pool takes 75 months to settle i.e. the system is able to recover from the skill shortages only after a duration of about 75 months for higher values of T_a. On the other hand, lower values of T_a indicate a smooth rise in the skill pool level for values of T_a ranging up to the first 23 months. The smooth rise is then followed by peak level i.e. at 230,000 units, followed by which the system response remains constant.

Actual Level of Competence Absorbed (ALCA)
Figure 5c shows the response of ALCA for a range of T_a values. Higher the values of T_a, more will be the time taken by ALCA to rise. Also, the number of graduates being absorbed becomes smaller compared to the lower values of T_r. The system takes 35 months to settle. However, for values of T_a ranging up to the first 10 months, there is a brief rise in the level of competence absorbed up to a duration of 35 months, after which the level remains constant indicating the settling of competence level.

3. Influence of Competence Training Delay Time (T_{dt})
Simulation was conducted with $T_r = T_a = T_{dr} = 6$ months (Maximum period for competency recovery) and T_{dt} was varied from 0 to 50 months.

Competence Training Completion Rate (CTCRATE)
Figure 6a illustrates the influence of T_{dt} on CTCRATE. The increase in T_{dt}; increases the time for rise, decreases peak value, increases settling time, and decreases TCRATE. Settling time is also very long (about 50 months). On the other hand, the smaller the T_{dt}, the less will be the time taken for CTCRATE to rise.

Actual Engineers Competence Pool Level (AECPL)
Figure 6b depicts that increasing the policy parameter T_{dt}; increases initial competence pool drop, increases the settling time and decreases the peak value. Settling time of 73 months is again on the higher side. Hence, it is very clear that for larger values of T_{dt} the system is unable to recover the competence pool shortage. On the other hand, for smaller values of T_{dt}, say the first 6 months, there would be a smooth recovery of competence pool with no fluctuations.

Actual Level of Competence Absorbed (ALCA)
The figure 6c shows the response of ALCA for a range of T_{dt} values. Higher the values of T_{dt}; the longer will be the time taken by ALCA to rise, and the smaller will be the number of graduates being absorbed. The system takes 70 months to settle. Minimal amount of fluctuations are observed for higher values of $T_{dt.}$ However, for values of T_{dt} ranging up to the first 5 months, there is a brief rise in the level of competence absorbed up to the duration of 23 months. After the 23rd month the level remains constant indicating that the competence level is settling.

4. Influence of Recruitment Delay Time (T_{dr})
Simulation was conducted with $T_r = T_a = T_{dt} = 6$ months (Maximum period for competency recovery) and T_{dr} was varied from 0 to 50 months.

Actual Level of Competence Absorbed (ALCA)
Figure 7 shows the response of ALCA for a range of T_{dr}. Again, the higher the values of T_{dr}; the longer will be the time taken by ALCA to rise. The system takes 80 months to settle for higher values of T_{dr}. A smooth rise in ALCA is observed for values of T_r ranging up to the first 3 months. This brief rise for the duration of about 12 months is followed by a sudden decrease in the level of competence absorbed. This sudden decrease is again followed by a sharp increase in the beginning of the 22nd month, after which the system response remains constant, indicating that the competence absorption level is settling.

Stage 2:

1. Influence of Competence Gap Recovery Time (T_r)
Simulation was conducted with $T_{dt} = T_a = 6$ months (Maximum period for competency recovery), $T_{rd} = T_{td} = T_{sl} = T_s = 3$ months and T_r is varied from 0 to 30 months.

Training Completion Rate (TCRATE)
The simulation result is shown in figure 8a. It depicts that smaller values of T_r will take less time for the TCRATE to rise to its peak value. But at the same time, this may result in

unwanted oscillations thereby increasing the settling time, which is clearly a case of bad system design as per the principles of control theory. Smaller T_r values also indicate that the rate at which people are being trained is high, and over a period of time this rate drops and settles quickly with one or two oscillations. But it takes a very long time (65 months) to settle down, which is highly impractical. However, the graph also depicts clearly that increasing T_r; increases the time for rise, decreases the peak value and decreases the TCRATE gradually.

Actual Level of Competence Absorbed (ALCA)

Figure 8b shows the response of ALCA for a range of values of time over which the competence gap is to be recovered (T_r). The higher the T_r values, the more will be the competence pool drop, indicating that the system is unable to recover from competency shortages over a period of time. Again, for higher values of T_r the system takes an unrealistically long time (60 months) to settle. However, for smaller values of T_r (about 5-6 months), there would be a smooth rise in competence level absorption with almost no oscillations. Once again, the settling time of about 60 months seems to be unrealistically long.

2. Influence of Competence Training Delay Time (T_{dt})

Simulation was conducted with T_r = T_a = 6 months (Maximum period for competency recovery), T_{rd} = T_{td} = T_{sl} = T_s = 3 months and T_{dt} was varied from 0 to 30 months.

Training Completion Rate (TCRATE)

Figure 9a illustrates the influence of T_{dt} on TCRATE. The increase in T_{dt}; increases the time for rise, decreases peak value, increases settling time, and decreases TCRATE slightly. Settling time is unrealistically long (65 months) and slight fluctuations in the TCRATE are observed for the duration of the first 43 months. On the other hand, the smaller the T_{dt}, the less will be the time taken by TCRATE to rise.

Actual Level of Competence Absorbed (ALCA)

Figure 9b depicts that increasing the policy parameter T_{dt}; increases initial competence pool drop, increases the settling time and decreases the peak value. Settling time of 65 months is again on the higher side. Hence, it is very clear that for larger values of T_{dt} the system is unable to recover the competence pool shortage. On the other hand, for smaller values of T_{dt}, say up to about 5-6 months, there would be a smooth recovery of competence pool absorption with minimum or almost no fluctuations.

3. Influence of Average time to determine the Forecast Competence Loss Rate (Ta)

Simulation was conducted with T_{dt} = T_r = 6 months (Maximum period for competency recovery), T_{rd} = T_{td} = T_{sl} = T_s = 3 months and T_a was varied from 0 to 30 months.

Training Completion Rate (TCRATE)

Figure 10a illustrates the influence of T_a on TCRATE. Increase in T_a; increases the time for rise slightly, decreases the peak value and decreases TCRATE slightly. Settling time for TCRATE is very high (65 months). Hence, it is clear that lower values of T_a will result in less time taken for the TCRATE to rise to its peak value. Settling time will also be slightly less for lower values of T_a.

Actual Level of Competence Absorbed (ALCA)
Figure 10b illustrates the influence of T_a on ALCA. Increase in T_a; increases the initial competence pool drop, increases the settling time, and decreases the peak value of ALCA. Settling time is unrealistically long (70 months). On the other hand, lower values of T_a indicate the smooth rise in the competence level and quick settling of ALCA. As the ALCA is continuously decreasing with the increase in T_a, delay in the calculation of average time to determine the forecast competence loss rate would badly affect ALCA.

4. Influence of Skill Gap Recovery Rate (T_s)
Simulation was conducted with $T_{dt} = T_a = T_r = 6$ months (Maximum period for competency recovery), $T_{rd} = T_{td} = T_{sl} = 3$ months and T_s is varied from 0 to 20 months.

Training Completion Rate (TCRATE)
Figure 11a illustrates the influence of T_s on TCRATE. The graph makes an important revelation that for a T_s value of less than 3 months, there are continuous fluctuations, which indicate aggressive hiring and firing policy. This could be due to various reasons, the dominant one being, an excessive supply of engineering manpower, which fails to acquire competence level required by the employers. Further, it is observed that increase in T_s; increases the time for rise, decreases the peak value and decreases the TCRATE gradually. The settling time would be about 30 months for T_s values greater than 3 months.

Actual Level of Competence Absorbed (ALCA)
The ALCA also shows rise & fall in the level of competence for the first 3 months (figure 11b). Increase in T_s; increases the initial competence pool drop slightly and decreases the peak value. The settling time for larger values of T_s will be unrealistically high (78 months). On the other hand, smaller values of T_s (<2 months) take less time to reach the ALCA.

5. Influence of Industrial Training Delay Time (T_{td})
Simulation was conducted with $T_{dt} = T_a = T_r = 6$ months (Maximum period for skill recovery), $T_s = T_{rd} = T_{sl} = 3$ months and T_{td} is varied from 0 to 20 months.

Training Completion Rate (TCRATE)
Figure 12a illustrates the influence of T_{td} on TCRATE. It reveals that increase in T_{td}; increases the time for rise slightly, increases the peak value considerably, and increases TCRATE gradually. It can also be observed that increase in T_{td} increases settling time considerably and even for the first 3 months the settling time is as high as 40 to 50 months, again indicating this to be a bad system as per the principles of control theory.

Actual Level of Competence Absorbed (ALCA)
The influence of T_{td} on ALCA is shown in figure 12b. Increase in T_{td}; increases the initial competence drop, increases the settling time to a great degree, and increases the peak value considerably. Again, the best results are possible only for the first 3 months, as there would be more fluctuations in the later stages. A settling time as high as 90 months indicates the bad system design in case of higher values of T_{td}.

6. Influence of Skill Loss Rate Averaging Time (T_{sl})
Simulation was conducted with $T_{dt} = T_a = 6$ months (Maximum period for competency recovery), $T_s = T_{rd} = T_{td} = 3$ months and T_{sl} was varied from 0 to 20 months.

Training Completion Rate (TCRATE)
Figure 13a illustrates the influence of T_{sl} on TCRATE. It reveals that increase in T_{sl}; decreases the time for rise, decreases the peak value of TCRATE initially (for $T_{sl} < 2$ months) followed by a gradual increase. Settling time is as high as 50 - 60 months, which is again, an indication of bad system design.

Actual Level of Competence Absorbed (ALCA)
The influence of T_{td} on actual level of competence absorbed is shown in figure 13b. Increase in T_{td}; increases the initial competence pool drop, increases the settling time and decreases the peak value marginally. Settling time is about 50 months, which indicates bad system.

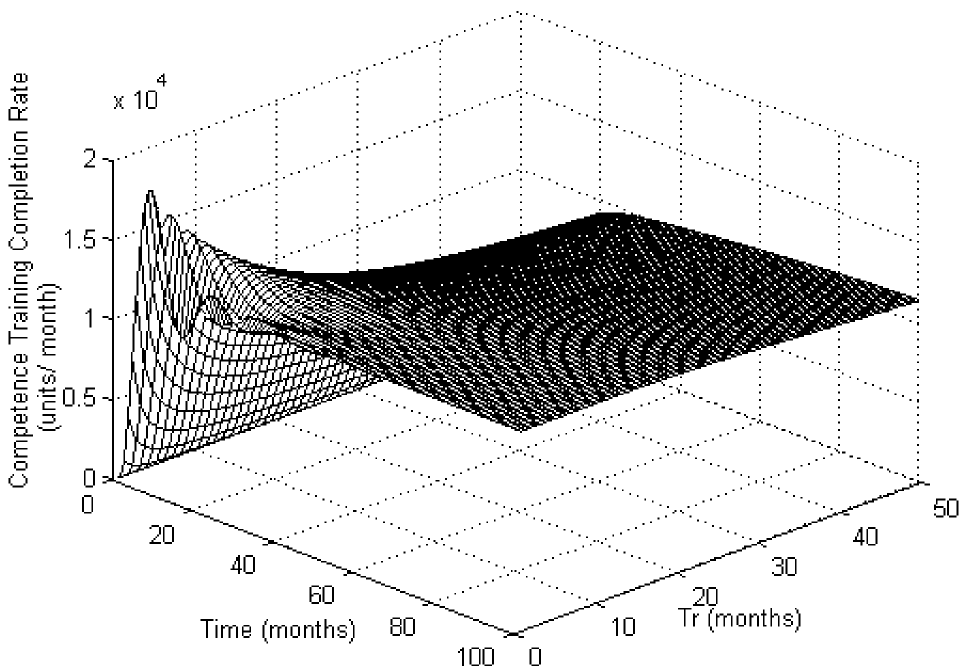

Figure 4a: Step response of GECOPM for varying values of T_r

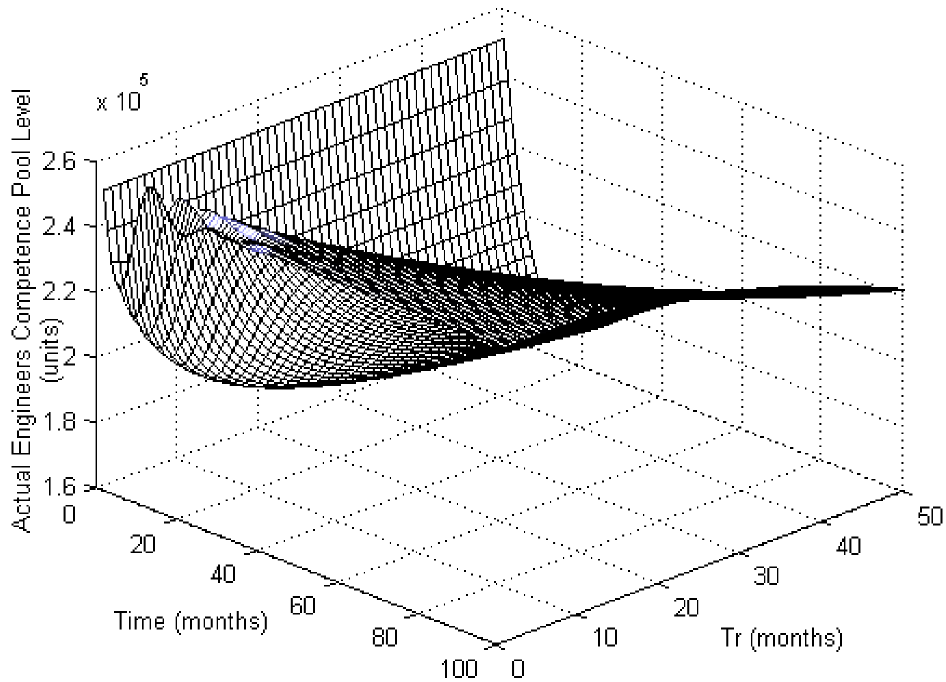

Figure 4b: Step response of GECOPM for varying values of T_r

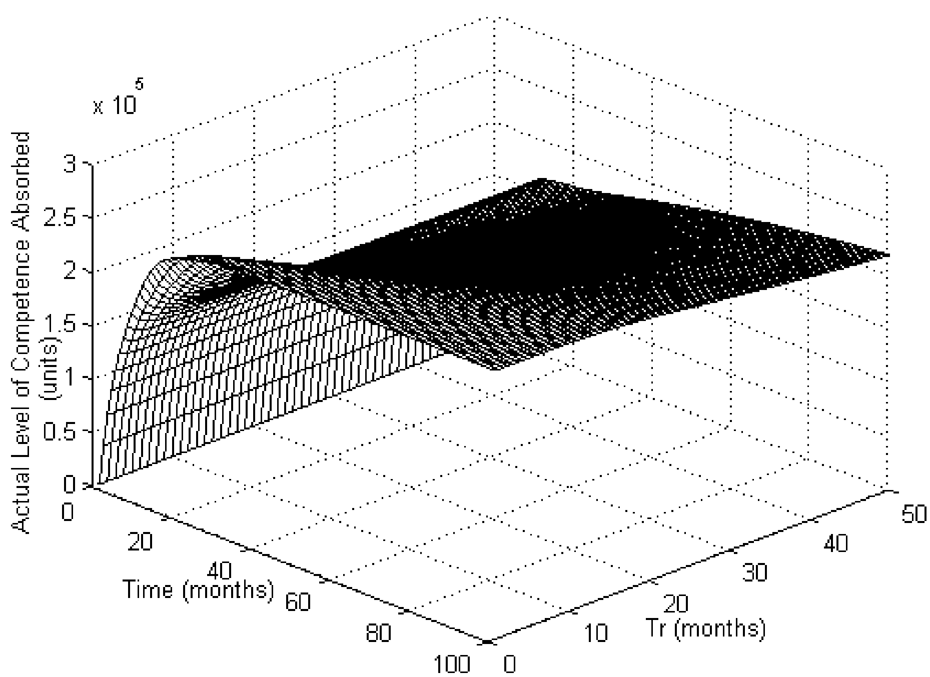

Figure 4c: Step response of GECOPM for varying values of T_r

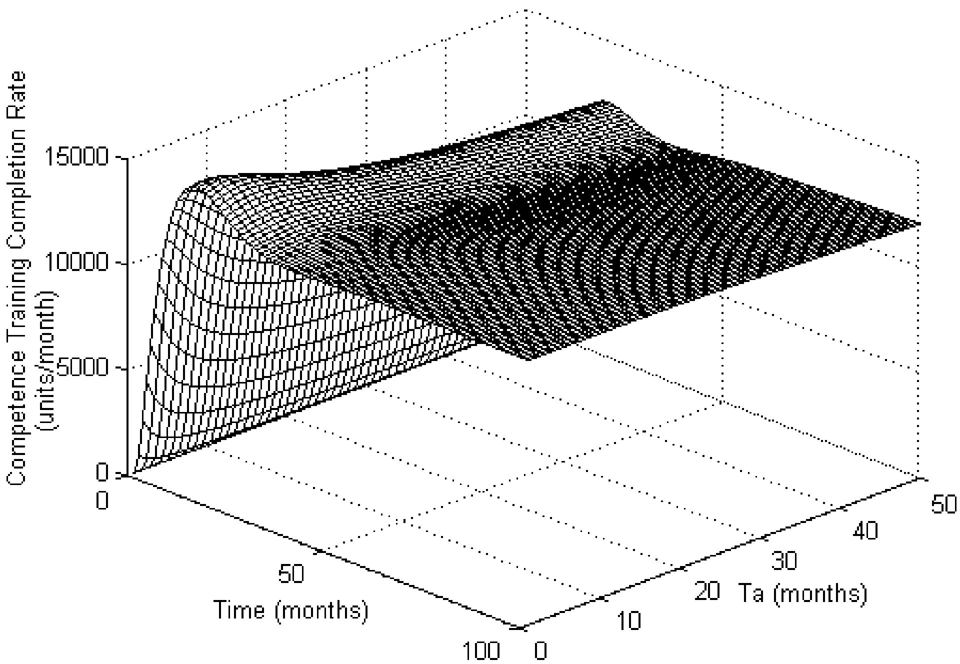

Figure 5a: Step response of GECOPM for varying values of T_a

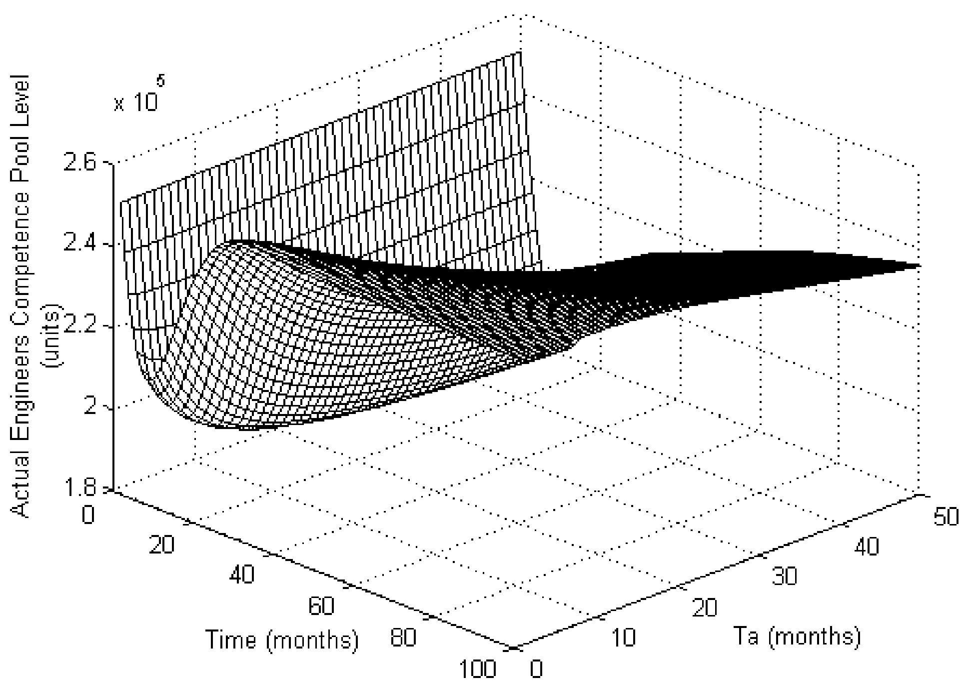

Figure 5b: Step response of GECOPM for varying values of T_a

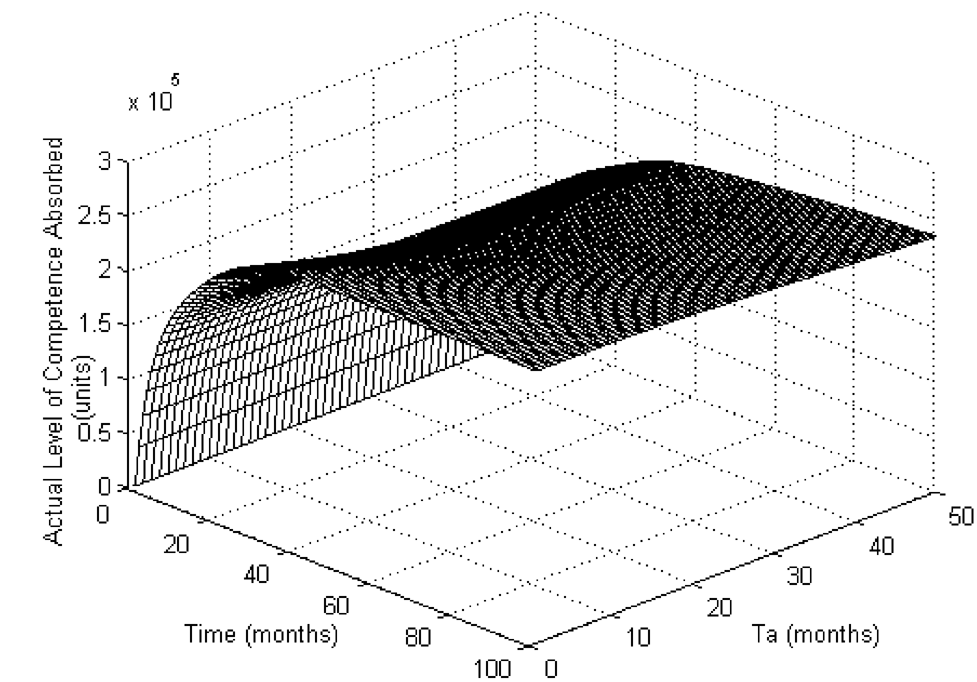

Figure 5c: Step response of GECOPM for varying values of T_a

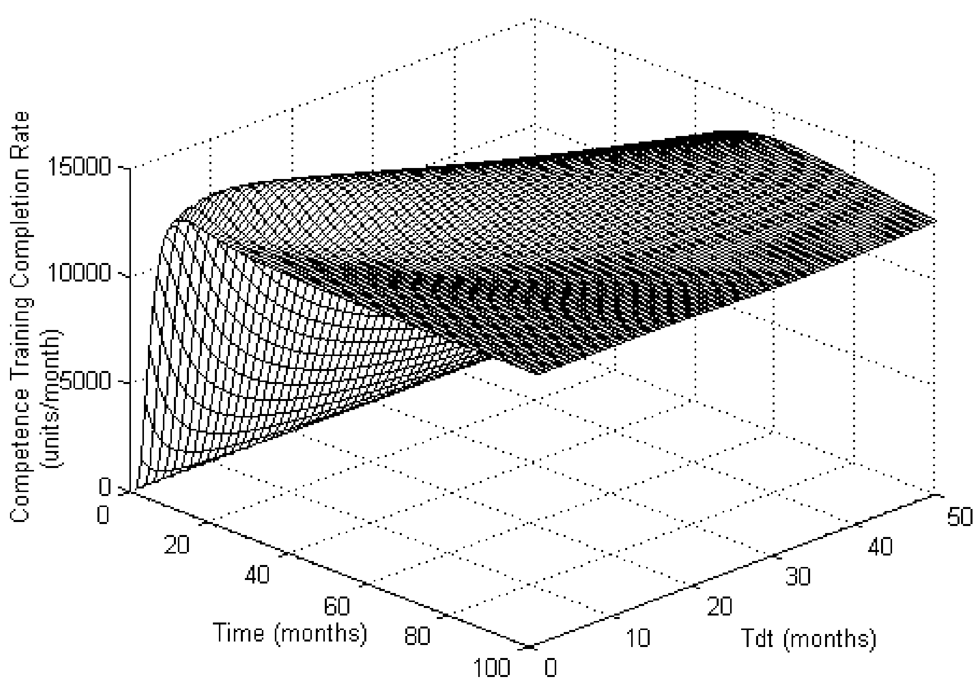

Figure 6a: Step response of GECOPM for varying values of T_{dt}

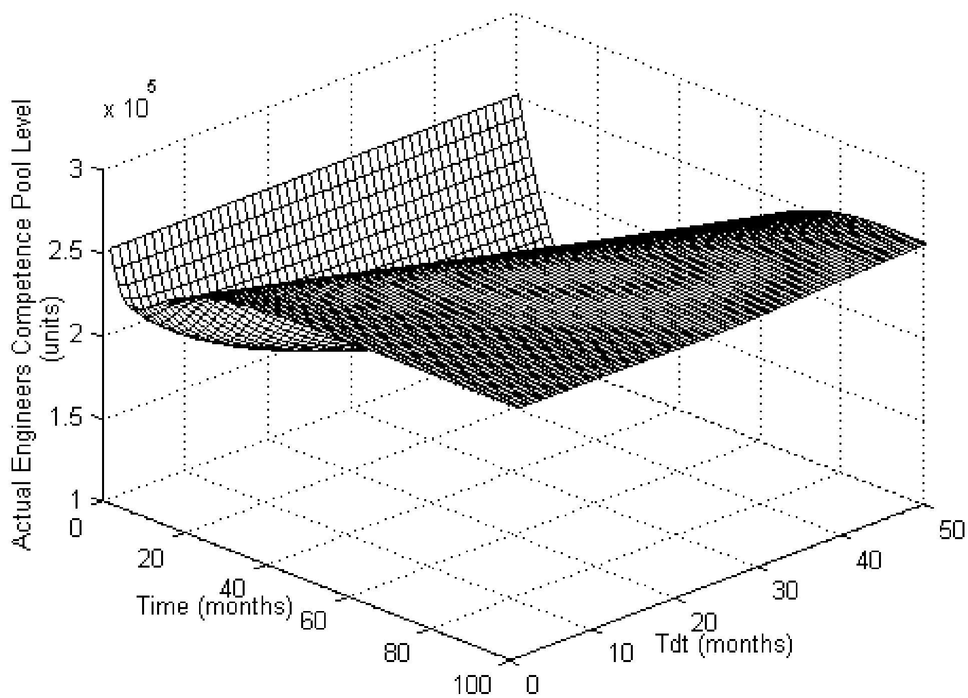

Figure 6b: Step response of GECOPM for varying values of T_{dt}

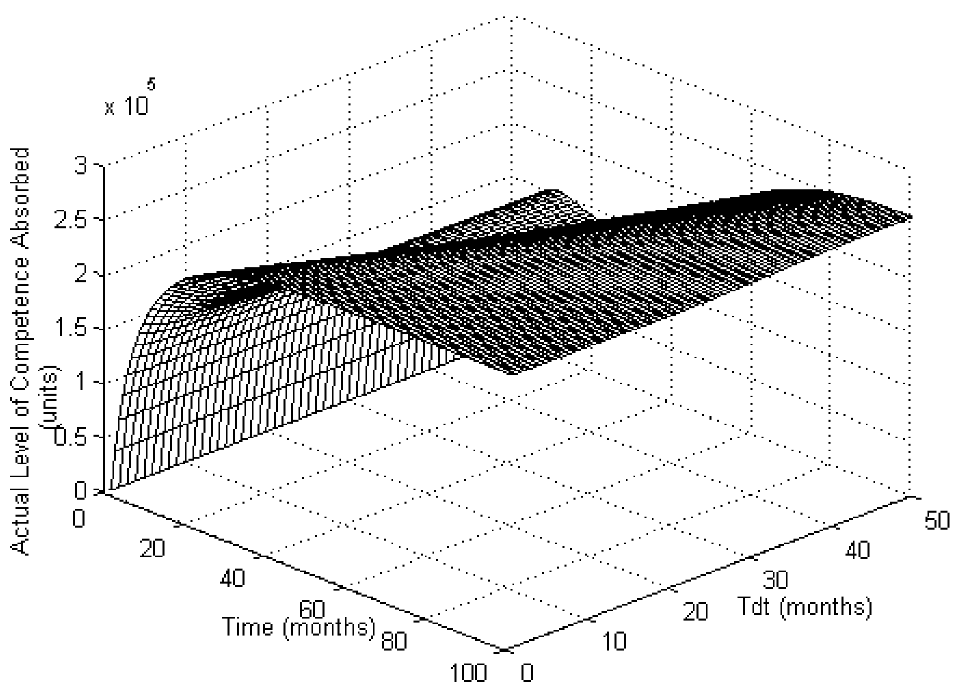

Figure 6c: Step response of GECOPM for varying values of T_{dt}

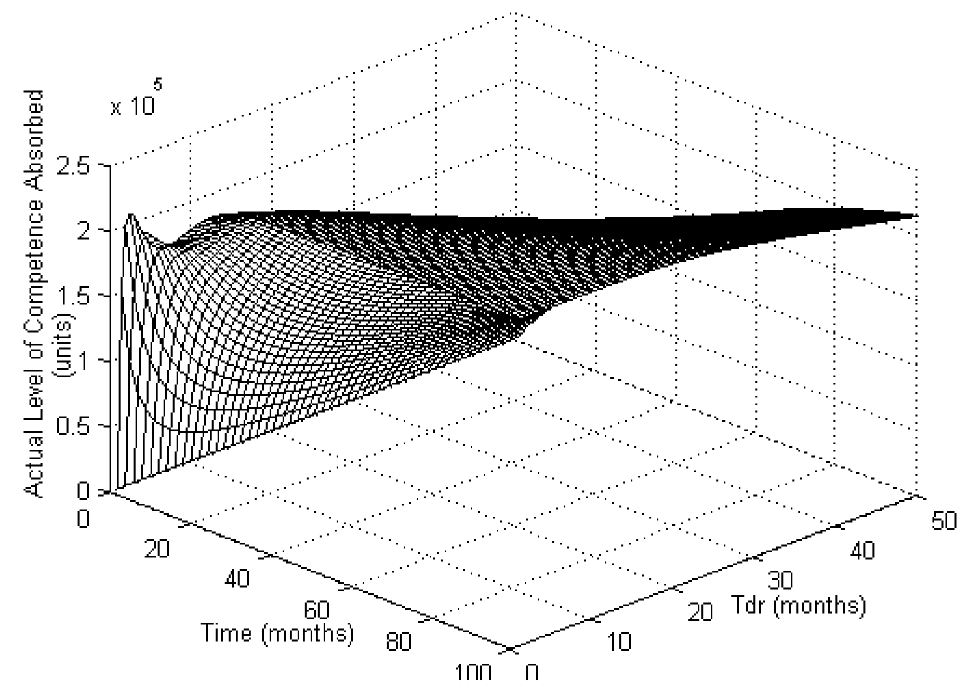

Figure 7: Step response of GECOPM for varying values of T_{dr}

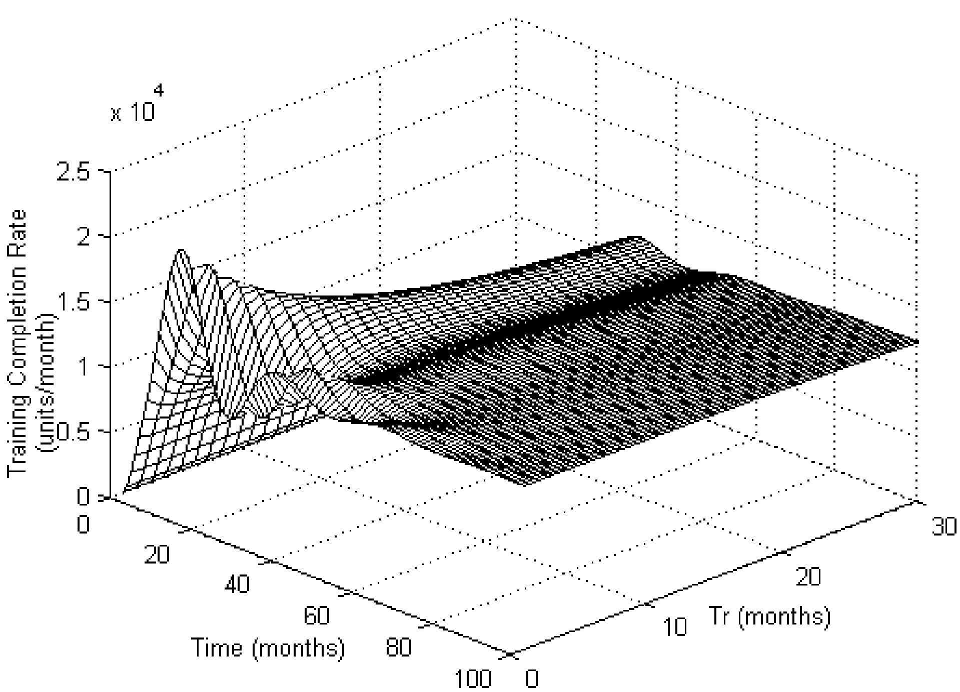

Figure 8a: Step response of PECOPM for varying values of T_r

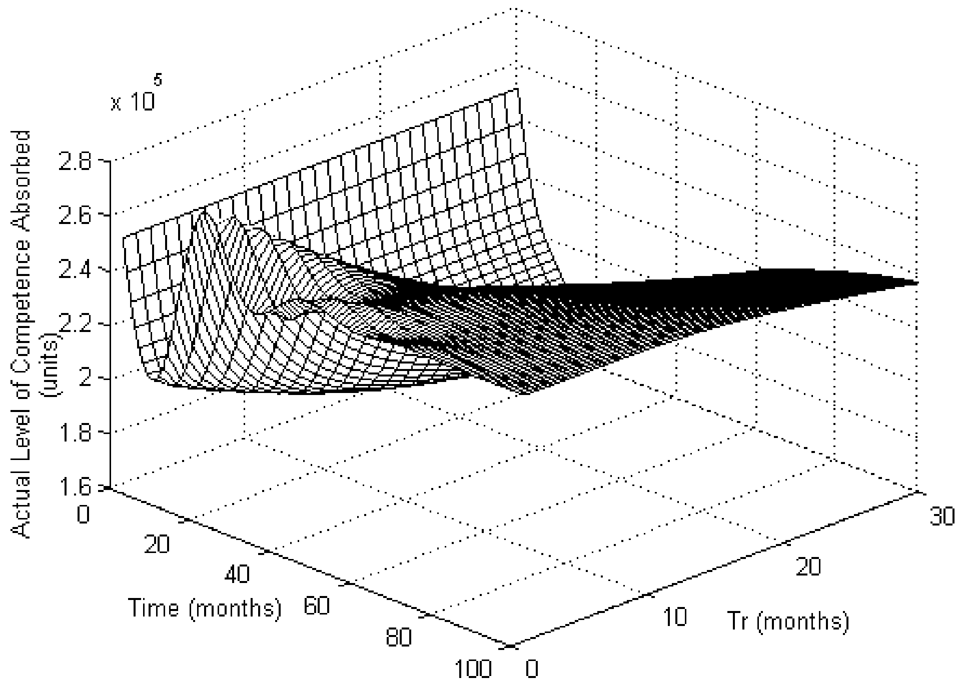

Figure 8b: Step response of PECOPM for varying values of T_r

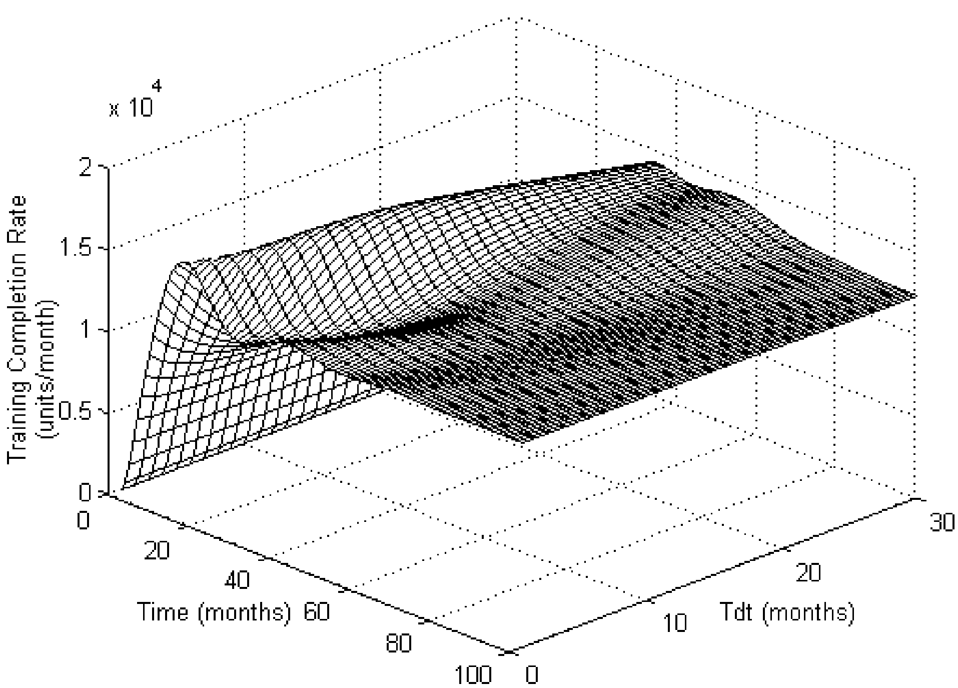

Figure 9a: Step response of PECOPM for varying values of T_{dt}

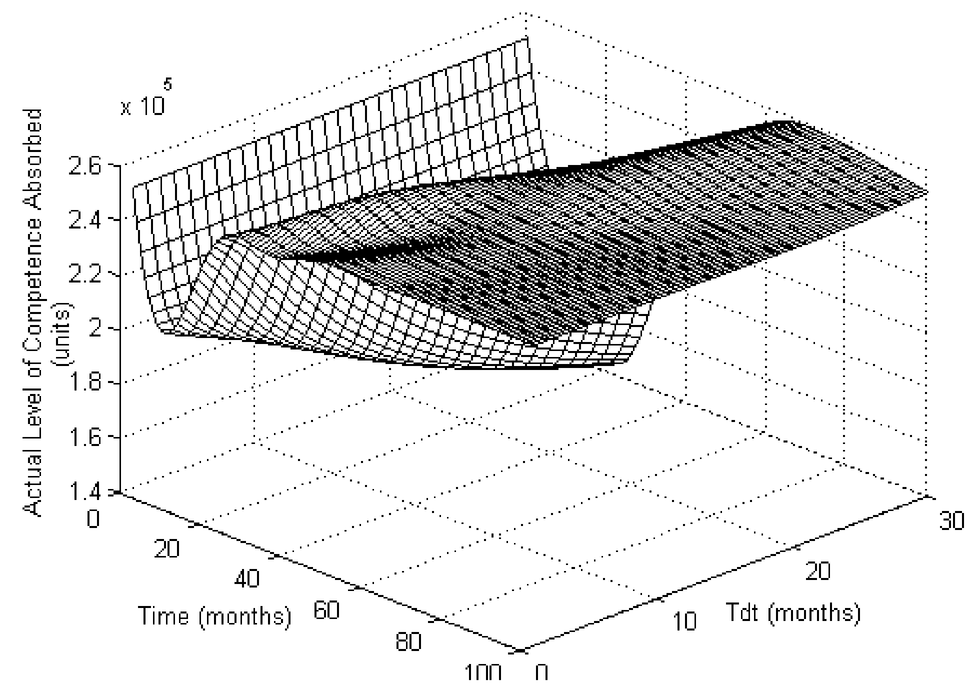

Figure 9b: Step response of PECOPM for varying values of T_{dt}

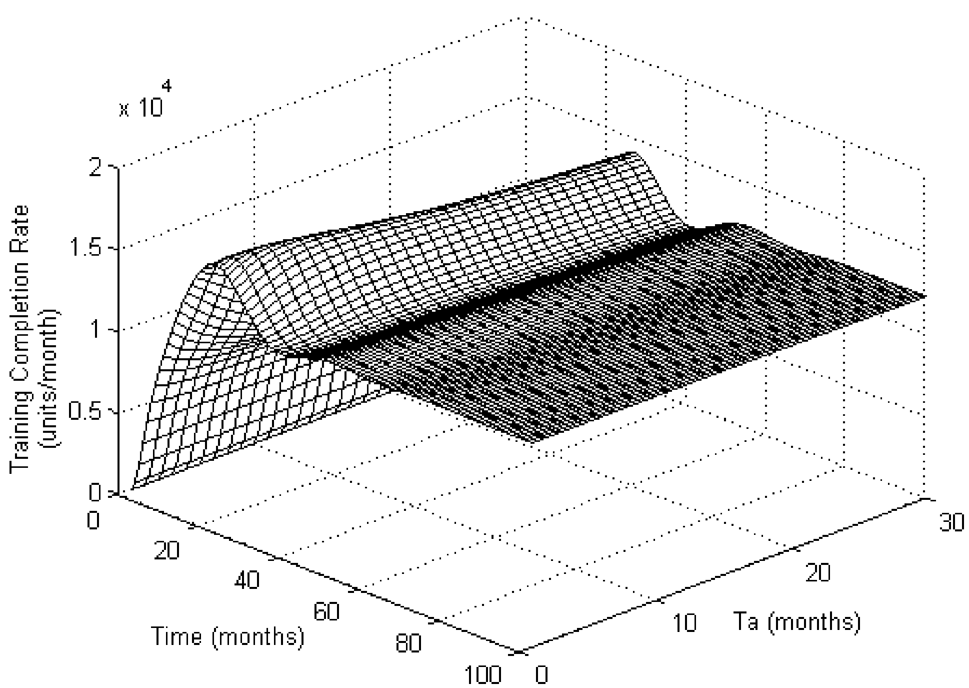

Figure 10a: Step response of PECOPM for varying values of T_a

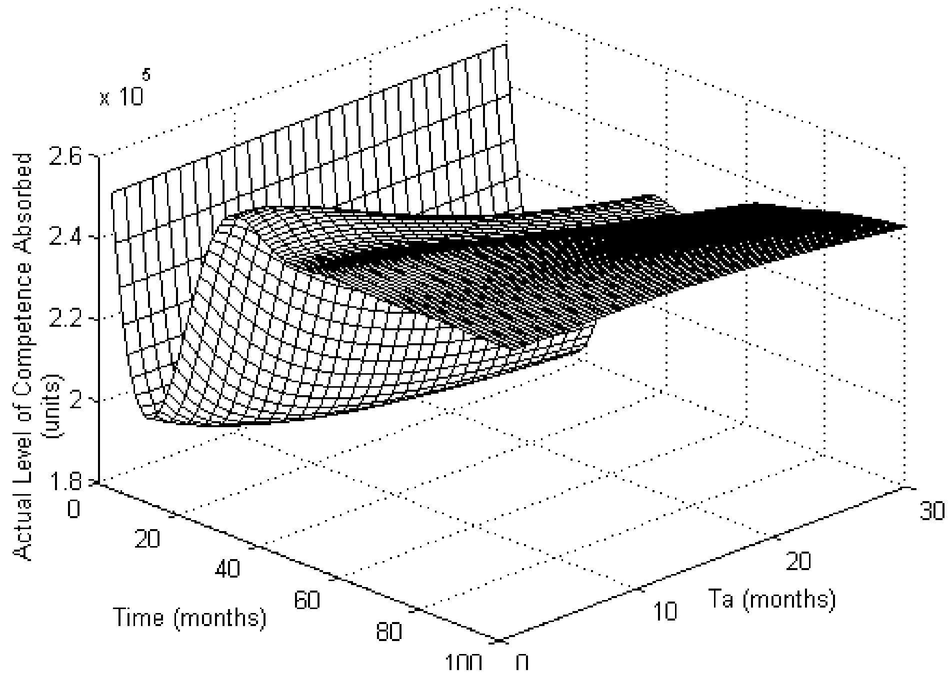

Figure 10b: Step response of PECOPM for varying values of T_a

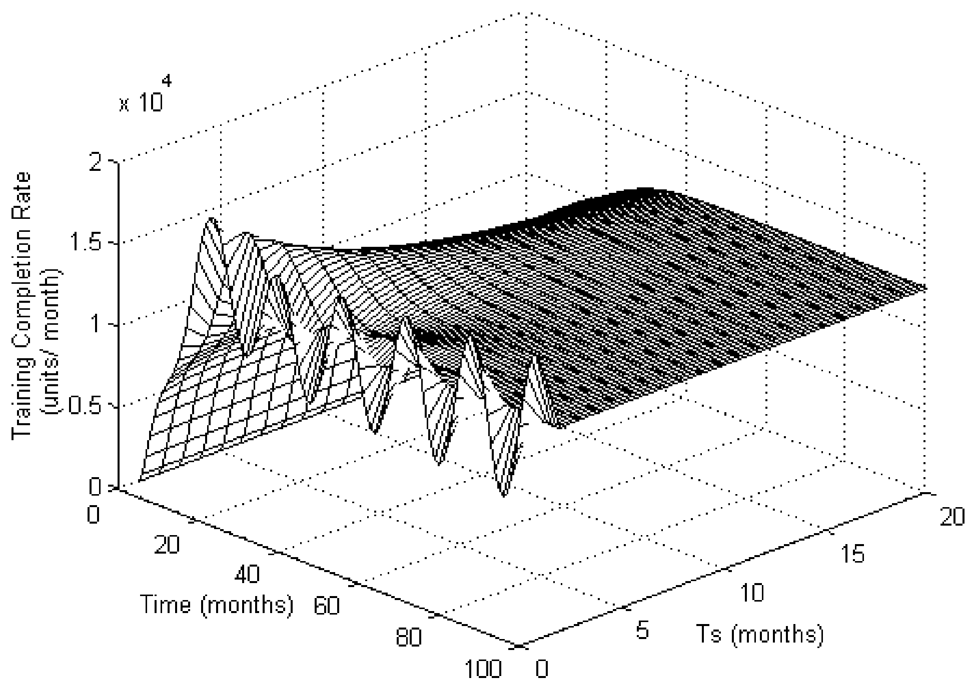

Figure 11a: Step response of PECOPM for varying values of T_s

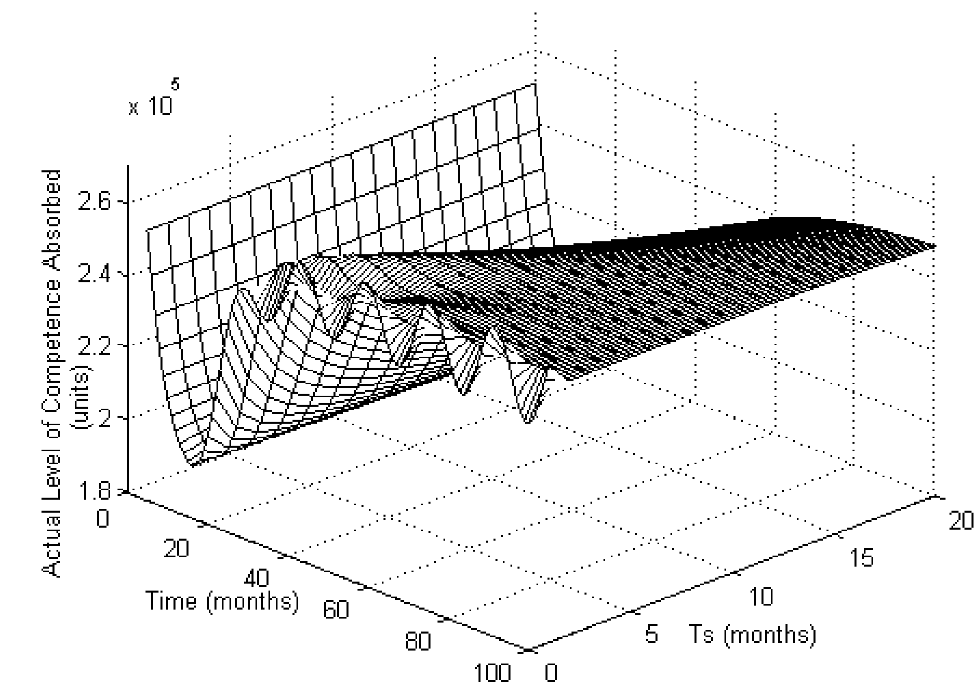

Figure 11b: Step response of PECOPM for varying values of T_s

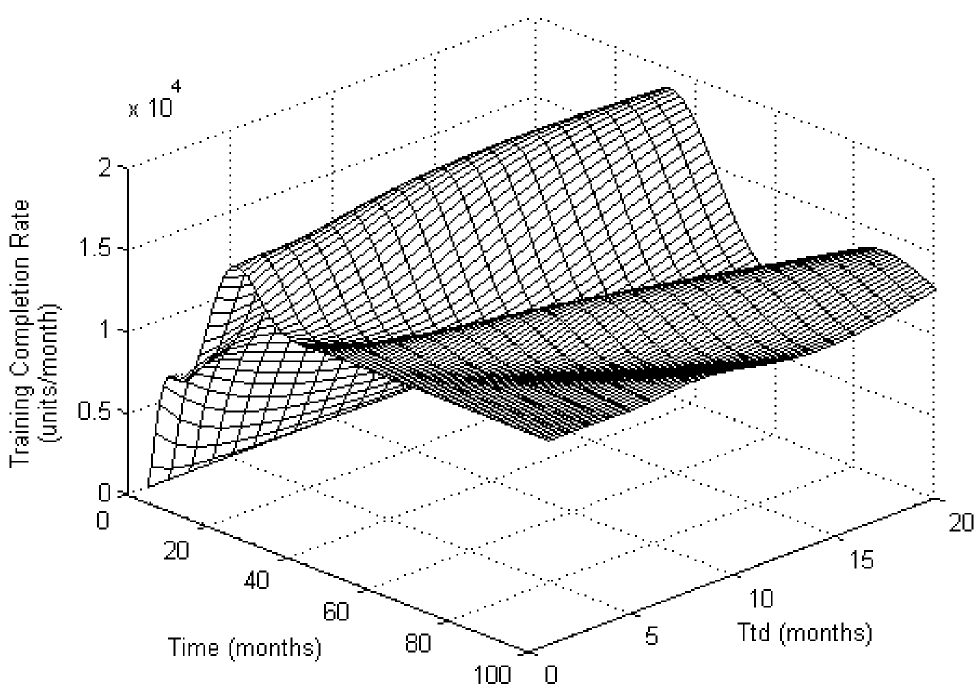

Figure 12a: Step response of PECOPM for varying values of T_{td}

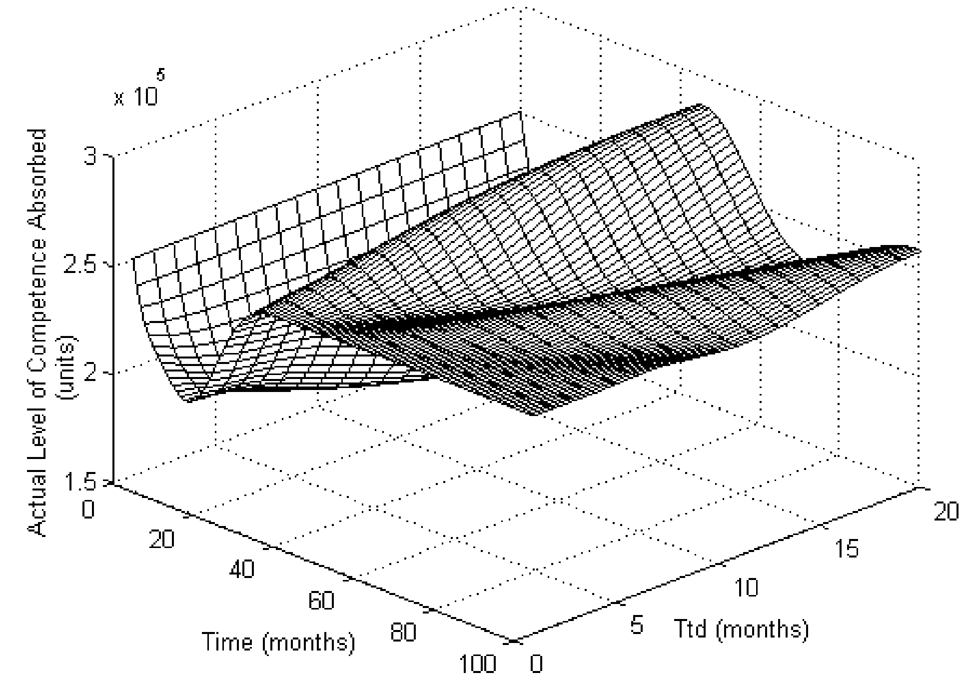

Figure 12b: Step response of PECOPM for varying values of T_{td}

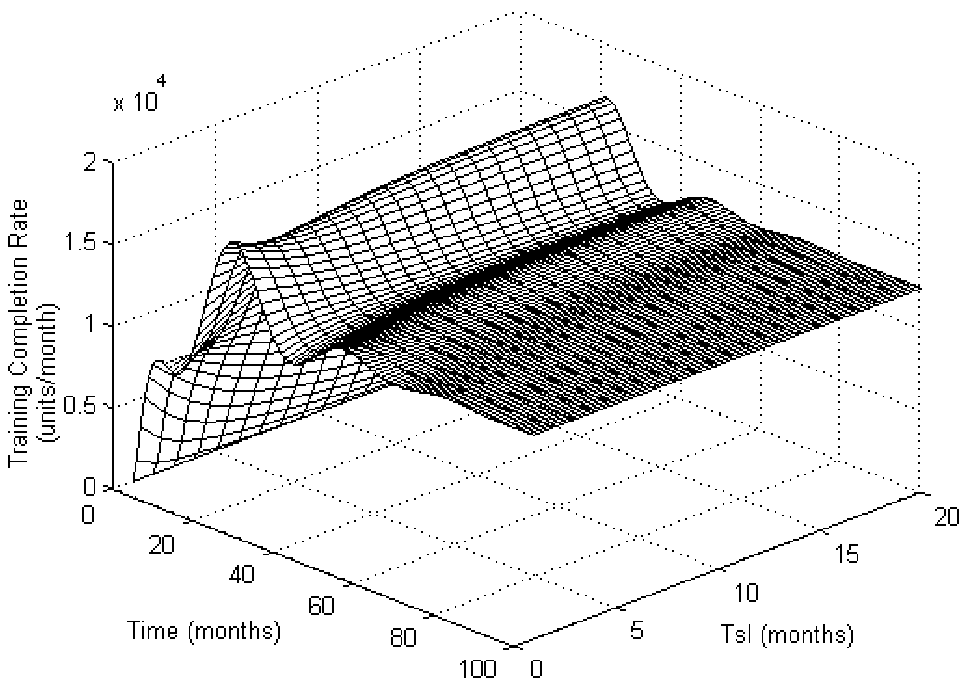

Figure 13a: Step response of PECOPM for varying values of T_{sl}

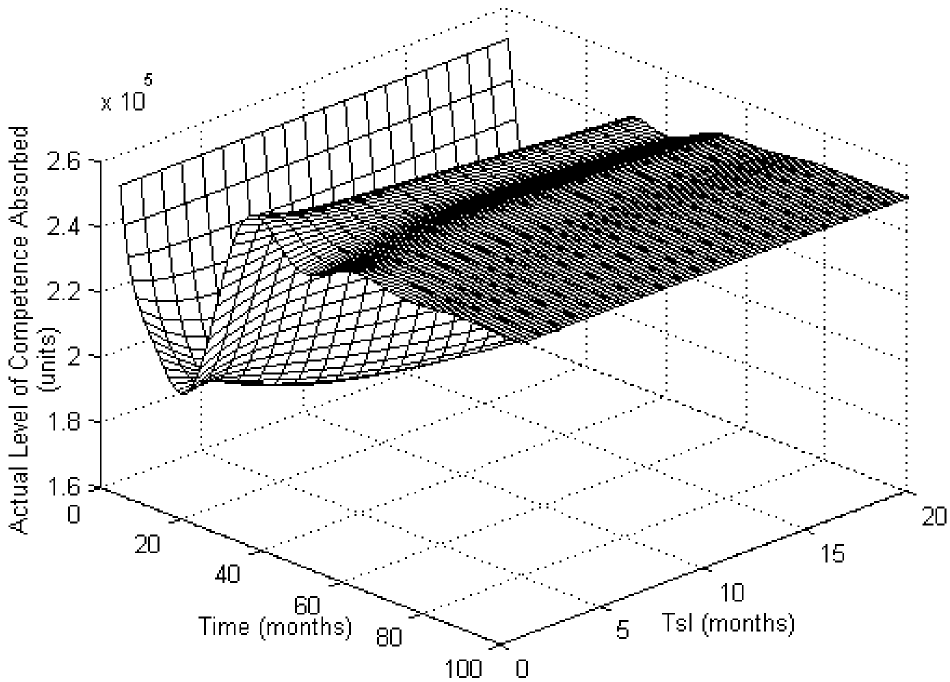

Figure 13b: Step response of PECOPM for varying values of T_{sl}

Comparative Analysis and Implications

Stage 1: Graduate Engineers' Competence Pool Model

The simulation results depict the relevance of the four time-based policy parameters on GECOPM. It can be observed that the time over which the competence gap is to be recovered (T_r) should be about 3 to 6 months to ensure good CTCRATE and to maintain a steady AECPL (Figure 4a & 4b). Also, to ensure a smooth rise in ALCA, T_r should not exceed 3 months (Figure 4c). The average time to determine the forecast competence loss rate (T_a) should not extend beyond 3 months with reference to CTCRATE and AECPL (Figure 5a & 5b). But for ALCA the ideal duration should not exceed 6 months (Figure 5c). Based on CTCRATE and AECPL, the T_{dt} should not exceed 3 months, and under no circumstances it should exceed 6 months (Figure 6a & 6b). This will also ensures smooth ALCA (Figure 6c). The Recruitment Delay Time (T_{dr}) must be kept to a minimum and should be about 3 to 6 months, during which there would also be a smooth ALCA (Figure 7).

By observing the influence of these policy parameters it can be concluded that the competence training delay time (T_{dt}) plays a crucial role in the system dynamics as it affects the stability of AECPL & CTCRATE. This is because higher T_{dt} values take longer time to settle, more time for rise and result in lower peak value in comparison with other policy parameters. Hence, for better results this is the key policy parameter, which demands a significant attention and control.

Stage 2: Practicing Engineers' Competence Pool Model

The simulation results have revealed the fact that all the six policy parameters chosen have considerable influence on the system dynamics of PECOPM. The time over which the competence gap is to be recovered (T_r) should be about 2 to 6 months, this ensures good TCRATE (Figure 8a) and a smooth rise ALCA (Figure 8b). The competence training delay time (T_{dt}) should be as short as possible, w.r.t. TCRATE and ALCA, the ideal being about 2 to 3 months (Figures 9a & 9b). The average time to determine the forecast competence loss rate (T_a) should not extend for more than 4 months for better TCRATE (Figure 10a), but with reference to the ALCA the ideal duration would be the first 2 months (Figure 10b). The skill gap recovery rate (T_s) has a significant influence on recruitment as the first few months may result in aggressive hiring and firing when there is over supply of engineers w.r.t. TCRATE (Figure 11a). Hence, in 4 – 6 months the fluctuations may settle down and peak recruitment may be ensured, which may also provide a smooth ALCA (Figure 11b). The industrial training delay Time (T_{td}) must be kept to a minimum and should not exceed 2 – 3 months w.r.t. TCRATE (Figure 12a), during which, there would also be a smooth ALCA (Figure 12b). Finally, the Skill Loss Rate Averaging Time (T_{sl}) should be between 3 to 6 months for the best results w.r.t. TCRATE and ALCA (Figure 13a & 13b). This would also ensure smooth skill absorption.

The above discussions delineate the fact that among the six policy parameters, Skill Gap Recovery Rate (T_s) plays the crucial role in the system dynamics of PECOPM as it affects the stability of the competence pool absorption. This is because higher T_s values take longer time to settle, more time for rise and result in lower peak value in comparison with the other policy parameters. Hence, for better results this is the key policy parameter, which demands a significant attention and control.

Conclusion

System Dynamics is a powerful tool, which can give an engineering solution to a non-engineering problem. This capability has been exploited in this paper through the development of the system dynamics model by organizing the structure and the information flows, using the cybernetics principles of causal relations.

The study of system dynamics of KM & HRM could be a very complicated phenomenon due to the influence of a myriad of time-based policy parameters. Choosing the most significant policy parameter and controlling it would surely enhance system performance but will remain a challenge due to the dynamic conditions, which influence the system. Two distinct stages i.e. GECOPM and PECOPM have been analyzed in this paper both of which deal with the integration of KM & HRM. The simulation results of GECOPM have indicated that the policy parameter T_{dt} (Competence Training Delay Time) has to be controlled for optimum system design. Similarly, in the case of PECOPM the policy parameter T_s (Skill Gap Recovery Rate) needs to be controlled. Both of these parameters need to be monitored closely, or else, the system would take longer time to settle, more time for rise and result in lower peak value in comparison with the other policy parameters.

This paper gives an in-depth study of the influence of major policy parameters on the integration of KM & HRM in engineering competence development and absorption. This could be a good source for policy makers to enhance the effectiveness of the system by adopting stringent methods to have proper control over the key policy parameters. In this knowledge driven economy, knowledge has been considered to be a strategic asset. So it goes without saying that creation, validation, utilization, storage and dissemination of knowledge, such that there would be a minimum competence gap, is not only a national concern but also a global concern in this progressive world of globalization. System dynamics has the potential to provide solution in seeking the optimum settings of the policy parameters.

Appendix Ia - Performance Index Table (Stage 1)

		Policy Parameters			
Performance Indices		**T_r**	**T_a**	**T_{dt}**	**T_{dr}**
Competence Training Completion Rate [CTCRATE]	Rise time	Increasing T_r slightly increases the time for rise	Increasing T_a slightly increases the time for rise	Increasing T_{dt} slightly increases the time for rise	NA
	Peak Overshoot	Increasing T_r decreases the peak value	Increasing T_a decreases the peak overshoot	Increasing T_{dt} increases the peak value	NA
	CTCRATE	Increasing T_r decreases the CTCRATE	Increasing T_a decreases the CTCRATE gradually	Increasing T_t decreases the CTCRATE gradually	NA
	Settling time	35 months [Figure 4a]	55 months [Figure 5a]	50 months [Figure 6a]	NA
Actual Engineers Competence Pool Level [AECPL]	Competence pool drop	Increasing T_r increases the competence pool drop	Increasing T_a increases the competence pool drop	Increasing T_{dt} increases the competence pool drop	NA
	Duration of competence pool deficit	Increasing T_r increases the settling time	Increasing T_a increases the settling time	Increasing T_{dt} increases the settling time	NA
	Peak competence pool overshoot	Increasing T_r decreases the peak value	Increasing T_a decreases the peak overshoot	Increasing T_{dt} decreases the peak values	NA
	Settling time	80 months [Figure 4b]	75 months [Figure 5b]	73 months [Figure 6b]	NA
Actual Level of Competence Absorbed [ALCA]	Rise time	Increasing T_r slightly increases the time for rise	Increasing T_a slightly increases the time for rise	Increasing T_{dt} increases the time for rise	Increase in T_{dr} increases the time for rise
	Settling time	60 months [Figure 4c]	30 months [Figure 5c]	70 months [Figure 6c]	80 months [Figure 7]

Appendix Ib - Performance Index Table (Stage 2)

		Policy Parameters					
Performance Indices		**T_r**	**T_{dt}**	**T_a**	**T_s**	**T_{td}**	**T_{sl}**
Training Completion Rate [TCRATE]	Rise time	Increasing T_r increases the time for rise	Increasing T_{dt}, increases the time for rise	Increasing T_a increases the time for rise slightly	Increasing T_s increases the time for rise	Increasing T_{td} increases the time for rise slightly	Increase in T_{sl} decreases the time for rise
	Peak Overshoot	Increasing T_r decreases the peak value	Increasing T_{dt} decreases the peak value	Increasing T_a decreases the peak value	Increasing T_s decreases the peak value	Increasing T_{td} increases the peak value gradually	Increase in T_{sl} decreases the peak value initially for T_s>2, followed by gradual increase
	Training Completion Rate	Increasing T_r decreases the TCRATE gradually	Increasing T_{dt} decreases the TCRATE slightly	Increasing T_a decreases the TCRATE slightly	Increasing T_s decreases the TCRATE gradually	Increasing T_{td} increases the TCRATE gradually	Increase in T_{sl} decreases the TCRATE initially followed by a gradual increase
	Settling time	65 months [Fig 8a]	65 months [Fig 9a]	65 months [Fig 10a]	30 months for T_s>3 [Fig 11a]	80 months [Fig 12a]	60 months [Figure 13a]
Actual Level of Competence Absorbed [ALCA]	Competence pool drop	Increasing T_r increases the competence pool drop	Increasing T_{dt} increases the competence pool drop	Increasing T_a increases the competence pool drop	Increasing T_s increases the competence pool drop slightly	Increasing T_{td}, increases the competence pool drop	Increase in T_{sl} increases the competence pool drop
	Duration of competence pool deficit	Increasing T_r increases the settling time	Increasing T_{dt} increases the settling time	Increasing T_a increases the settling time	Increase in T_s increases the settling time for T_s>2	Increasing T_{td} increases the settling time	Increase in T_{sl} increases the settling time
	Competence pool overshoot	Increasing T_r decreases the peak value	Increasing T_{dt} decreases the peak value	Increasing T_a decreases the peak value	Increasing T_s decreases the peak value	Increasing T_{td} increases the peak value	Increase in T_{sl} decreases the peak value
	Settling time	60 months [Fig 8b]	65 months [Fig 9b]	70 months [Fig 10b]	78 months [Fig 11b]	90 months [Fig 12b]	50 months [Fig 13b]

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