System Dynamics Approach to an Ergonomics Model

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Abstract

A poor ergonomics culture is one of the major causes of serious injuries in the manufacturing industries. Improving an ergonomics culture assists an organization to reduce the incident rates, leading to better work performance, lower compensation costs, and higher productivity. This paper developed an ergonomics dynamic model utilizing the system dynamics modeling to capture the interactions among key ergonomics factors, namely Leadership, Policy and Strategy, Resources, Processes, Customer Satisfaction, and Financial Results, over time. The equations relating to the factors and the relationships among them were demonstrated in details in this paper. It was expected that the developed dynamic model helped identifying areas for ergonomics culture improvement.

Keywords: Ergonomics culture, ergonomics dynamic model, maturity levels, system dynamic modeling.

Introduction

Ergonomics is concerned with the 'fit' between people and their work (The Ergonomic Society, 2008). It takes account of the worker's capabilities and limitations in seeking to ensure that tasks, equipment, information and the environment suit each worker. To assess the fit between a person and their work, ergonomists consider the job being done and the demands on the worker; the equipment used, and the information used. Nanthavanij (2010) stated that the objectives of ergonomics implementation are to maximize human contribution to the system performance and to minimize the system impact on human.

Ergonomics can be applied into many industries, such as aerospace, aging, health care, information technology, product design, transportation, training, and nuclear and virtual environments. For example, Krajewski et al. (2007) investigated the implementation of an ergonomics process designed to identify and reduce exposures to ergonomic risk factors found in a US coal mine. Helander (1997) studied the ergonomics improvement at the IBM plant in Austin, Texas, and listed such improvements as the improved communication and housekeeping, and noise reduction.

There are many ways to apply ergonomics in the manufacturing environment. One approach that addresses ergonomics at all levels of an organization is to grow an "ergonomics culture" (McDonald et al., 2002). Doing this, the organizations must look into five major enablers, including Leadership, Policy and Strategy, People, Resources, and Processes, and that all of these five enablers interact and affect the system output, both Customer Satisfaction and Financial Results (EFQM, 1998; Lee, 2005).

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There was also a need to examine the interrelationships among the key ergonomics factors over time, so that the organizations could effectively plan for ergonomics improvement. Moreover, organizations should realistically assess their ergonomics culture maturity level, and progress through to higher levels of maturity. This paper, thus, developed an ergonomics dynamic model to capture the interactions among the key ergonomics enablers and results, and their consequences over time. The ergonomics maturity level, achieved from the dynamic model, was also used to plan for ergonomics improvement.

A Proposed Ergonomics Model

According to Lee (2005) and Chinda and Rittippant (2010), an ergonomics model was developed based on the widely used international quality models, the EFQM Excellence model, together with the TQM model. The ergonomics model consists of five 'enablers', including Leadership (Lds), Policy and Strategy (Pol), People (Ppl), Resources (Rsr), and Processes (Pro), to achieve two major 'results', namely Customer Results (Csr) and Key Performance Results (Kpr). The causal links were examined using the statistical technique of structural equation modeling to gain an understanding of the interrelationships among the different factors of ergonomics, as shown in Figure 1 (Chinda and Rittippant, 2010). It was cleared that leader plays a key role in setting up the ergonomics policies and strategies (with the coefficient of 0.91 between Lds and Pol), and that these strategies can be used to motivate people, and support with the necessary resources to implement ergonomics effectively. The Pol enabler was found having an indirect relationship with Pro through Ppl and Rsr factors. Good ergonomics policies and strategies undoubtedly assisted employees in acquiring necessary resources to implement ergonomics. The Pro enabler, on the other hand, had a strong influence in achieving higher customer satisfaction. This could be seen from a strong path coefficient of 0.85 from Pro to Cus factors.

In addition to the causal links, the criterion weights were also an important part of the model. Based on the EFQM (1998), a total of 1,000 points of the ergonomics model is evenly split (500/500) between the enablers and results. The 500 points allocated to the enablers are distributed as follows: 100 points to Lds, 80 points to Pol, 90 points to Ppl, 90 points to Rsr, and 140 points to Pro. Adapted from EFQM (1998), the 285 points of results are allocated to Csr and 215 points to Kpr. At any point of time, the scores of these seven factors were summed up to form an aggregated score, called the 'total ergonomics' score. This total score, ranging from a minimum of 0 point to a maximum of 1,000 points, was used to assess the current levels of ergonomics maturity that were divided into five levels: level 1 ranges from 0 – 99 points, level 2 from 100 – 299 points, level 3 from 300 – 649 points, level 4 from 650 – 749 points, and level 5 from 750 - 1,000 points (Dale and Smith, 1997).
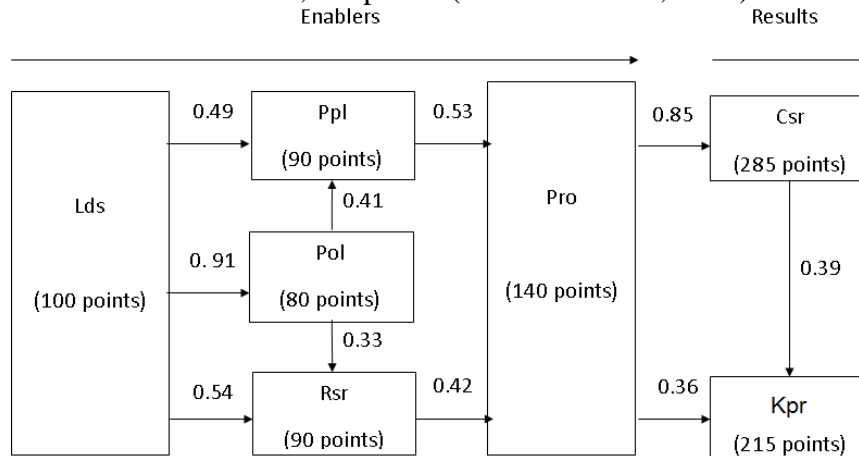

Figure 1. A Proposed Ergonomics Model

An Ergonomics Dynamic Model Development

An ergonomics dynamic model, as shown in Figure 2, was developed utilizing the system dynamics modeling technique. This technique has commonly been used when feedback loops are critical to the understanding of the interrelationships (Rodrigues and Bowers, 1996). The model captured the interactions among the seven factors, with a maximum 'total ergonomics score' of 1,000 points. The model assumed that when the organization focuses on improving the five enablers to achieve better results, the total ergonomics score could be higher. The anonyms used in the model are as below.

Actual_Csr	= Actual score of Customer Satisfaction
Actual_Lds	= Actual score of Leadership
Actual_Pol	= Actual score of Policy and Strategy
Actual_Ppl	= Actual score of People
Actual_Pro	= Actual score of Processes
Actual_Rsr	= Actual score of Resources
Adjusted_results	= Adjusted Results' score
Csr_rate	= Customer Satisfaction rate
Csr(t)	= Customer Satisfaction value at t time period
Csr(t-dt)	= Customer Satisfaction value at t-dt time period
Find_gap_rate_Lds	= Find gap rate of Leadership
Find_gap_rate_Pol	= Find gap rate of Policy and Strategy
Find_gap_rate_Ppl	= Find gap rate of People
Find_gap_rate_Pro	= Find gap rate of Processes
Find_gap_rate_Rsr	= Find gap rate of Resources
Gap_lds	= Gap of Leadership
Gap_Pol	= Gap of Policy and Strategy
Gap_Ppl	= Gap of People
Gap_Pro	= Gap of Processes
Gap_Rsr	= Gap of Resources
Kpr_rate	= Key Performance Results rate
Kpr(t)	= Key Performance Results value at t time period
Kpr(t-dt)	= Key Performance Results value at t-dt time period
Lds_fraction	= Leadership fraction
Lds_rate	= Leadership rate
Lds(t)	= Leadership value at t time period
Lds(t-dt)	= Leadership value at t-dt time period
ML_growth_rate_lvl1	= Growth rate of maturity level 1
ML_growth_rate_lvl2	= Growth rate of maturity level 2
ML_growth_rate_lvl3	= Growth rate of maturity level 3
ML_growth_rate_lvl4	= Growth rate of maturity level 4
ML_growth_rate_lvl5	= Growth rate of maturity level 5
Out_Csr	= Outflow of Customer Satisfaction
Out_Kpr	= Outflow of Key Performance Results
Out_Lds	= Outflow of Leadership
Out_Pol	= Outflow of Policy and Strategy
Out_Ppl	= Outflow of People
Out_Pro	= Outflow of Processes
Out_Rsr	= Outflow of Resources
Pol_fraction	= Policy and Strategy fraction
Pol_rate	= Policy and Strategy rate

Pol(t)   = Policy and Strategy value at t time period
Pol(t-dt)   = Policy and Strategy value at t-dt time period
Ppl_fraction   = People fraction
Ppl_rate   = People rate
Ppl(t)   = People value at t time period
Ppl(t-dt)   = People value at t-dt time period
Pro_rate   = Processes rate
Pro(t)   = Processes value at t time period
Pro(t-dt)   = Processes value at t-dt time period
Real_Csr   = Real value of Customer Satisfaction
Real_gap_lds   = Real gap of Leadership
Real_Kpr   = Real value of Key Performance Results
Real_Lds   = Real value of Leadership
Real_Pol   = Real value of Policy and Strategy
Real_Ppl   = Real value of People
Real_Pro   = Real value of Processes
Real_Rsr   = Real value of Resources
Results   = Results score
Results_to_lds   = Results score sent to Leadership
Rsr_fraction   = Resources fraction
Rsr_rate   = Resources rate
Rsr(t)   = Resources value at t time period
Rsr(t-dt)   = Resources value at t-dt time period

The dynamic model of each construct is discussed next.

Leadership Dynamic Model

The leadership dynamic model was represented by the stock and flow. The increase in the 'Lds_rate' flow depended on the 'gap of leadership score' (Gap_lds), the 'leadership fraction' (Lds_fraction), and the 'results score to leadership' (Results_to_lds), as shown in Equations 1 and 2.

$$Lds(t) = \quad Lds(t\text{-}dt)+(Lds\_rate)*dt \qquad\qquad (1)$$
$$Lds\_rate = (Results\_to\_lds+Gap\_lds)*Lds\_fraction \qquad\qquad (2)$$

The 'Results_to_lds' was calculated based on the 'Adjusted_results', which took the maturity levels into account (see Equations 3 and 4). To explain, the 'Results' scores were divided into five ranges (49.5, 149.5, 324.5, 374.5, and 500 points, respectively, see Equation 3) to match with the five level of ergonomics maturity. The 'gap of leadership score' (Gap_lds) was, on the other hand, illustrated in Equation 5. In this equation, the 'Real_Lds' scores were also divided into five levels to match with the ergonomics maturity levels (i.e. 10, 30, 65, 75, and 100 points, respectively).

Results_to_Lds = if(Results<=49.5)then(Adjusted_results*ML_growth_rate_lvl1)
                  else if(Results<=149.5)then(Adjusted_results*ML_growth_rate_lvl2)
                  else if(Results<=324.5)then(Adjusted_results*ML_growth_rate_lvl3)
                  else if(Results<=374.5)then(Adjusted_results*ML_growth_rate_lvl4)
                  else if(Results<=500)then(Adjusted_results*ML_growth_rate_lvl5)
                  else (Adjusted_results*ML_growth_rate_lvl5)   (3)
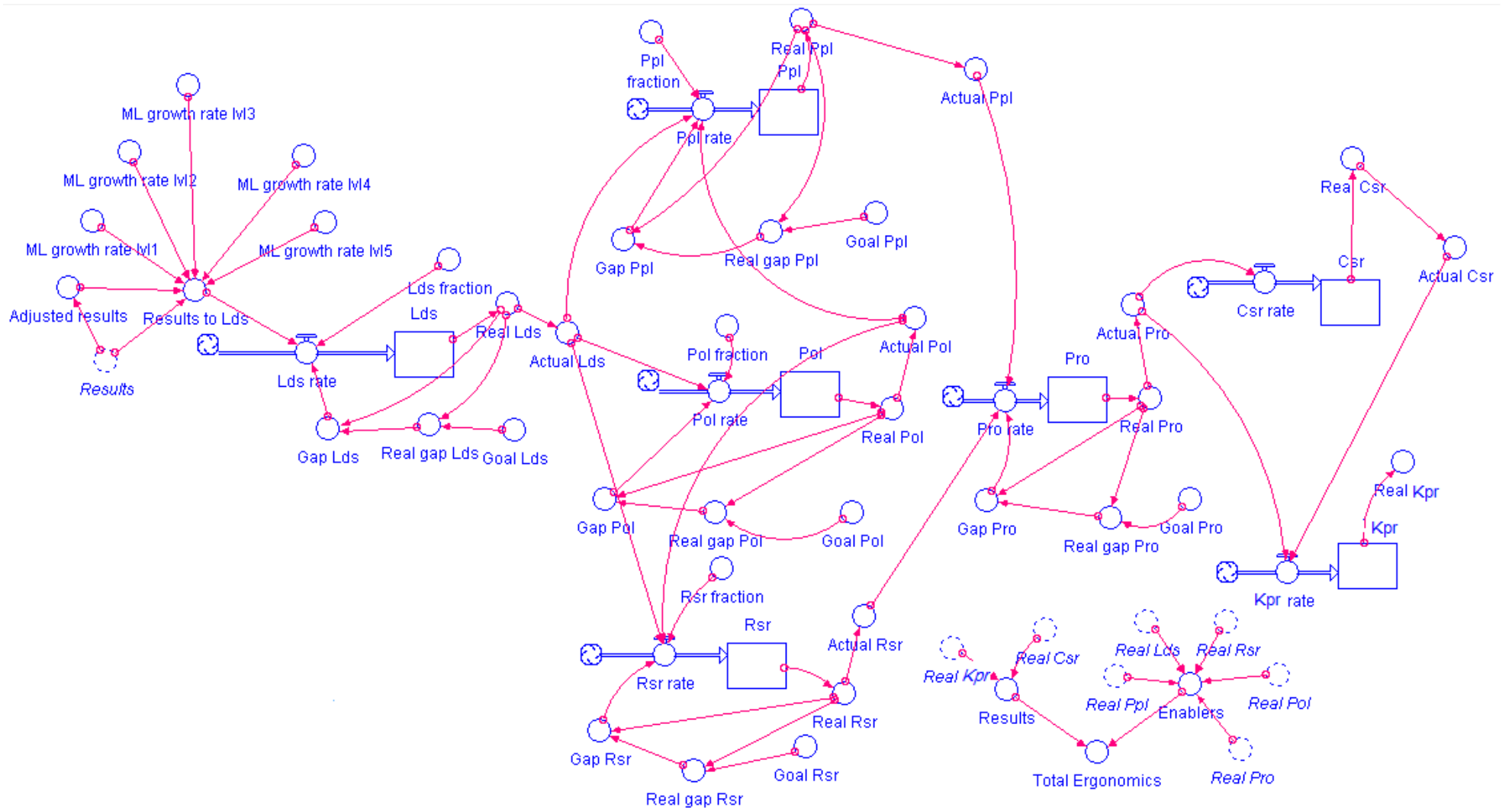
Figure 2. An Ergonomics Dynamic Model

$$\text{Adjusted\_results} = \text{if(Results}\leq49.5)\text{then(Results)else if(Results}\leq149.5)\text{then}$$
$$\text{(Results-49.5)else if(Results}\leq324.5)\text{then(Results-149.5)}$$
$$\text{else if(Results}\leq374.5)\text{then(Results-324.5)else if}$$
$$\text{(Results}\leq500)\text{then(Results-374.5) else(Results-374.5)} \qquad (4)$$

$$\text{Gap\_lds} = \text{if(Real\_Lds}\leq10)\text{then(Real\_gap\_lds*0.1)else if(Real\_Lds}\leq30)\text{then}$$
$$\text{(Real\_gap\_lds*0.2)else if(Real\_Lds}\leq65)\text{then(Real\_gap\_lds*0.35)else if}$$
$$\text{(Real\_Lds}\leq75)\text{then(Real\_gap\_lds*0.1)else if(Real\_Lds}\leq100)\text{then}$$
$$\text{(Real\_gap\_lds*0.25)else(Real\_gap\_lds*0.25)} \qquad (5)$$

Given that Lds was assumed to drive Ppl, Pol, and Rsr; the newly obtained 'Actual_Lds' value, as illustrated in Equation 6, was transferred to these three connected dynamic models. This transferred value was, however, influenced by the path coefficients between Lds and the three constructs, as demonstrated in Figure 1.

$$\text{Actual\_Lds} = \text{if(Real\_Lds}\leq10)\text{then(Real\_Lds)else if(Real\_Lds}\leq30)\text{then}$$
$$\text{(Real\_Lds-10)else if(Real\_Lds}\leq65)\text{then(Real\_Lds-30)else if}$$
$$\text{(Real\_Lds}\leq75)\text{then(Real\_Lds-65)else if(Real\_Lds}\leq100)\text{then}$$
$$\text{(Real\_Lds-75)else(Real\_Lds-75)} \qquad (6)$$

Policy and Strategy Dynamic Model

Lds influenced the establishment of ergonomics policy and strategies in the organization, leading to the flows of the 'Actual_Lds' value into the 'policy and strategy rate' (Pol_rate), as shown in Equations 7 to 10. The 'Actual_Lds' value, shown in Equation 8, was multiplied by the constant value of 0.47, which was derived from the adjusted path coefficient from Lds to Pol (0.91/(0.49+0.91+0.54), see Figure 1). The 'Real_Pol' scores, shown in Equations 9 and 10, were as well divided to match with the five maturity levels (i.e. 8, 24, 52, 60, and 80 points, respectively). The 'Gap_Pol', revealed in Equation 9, was multiplied by constant values of 0.1, 0.2, 0.35, 0.1, and 0.25, respectively. These constant values were based on the range of the Pol scores in each maturity level. To illustrate, the Pol score in level 1 was maximized at 8 points; this is 8 out of the maximum of 80 points, leading to the proportion of $8/80 = 0.1$. Pol score in level 2 was, on the other hand, maximized at 24 points; this proportion of this level was then $(24 - 8)/80 = 0.2$.

$$\text{Pol(t)} = \text{Pol(t-dt)+(Pol\_rate)*dt} \qquad (7)$$
$$\text{Pol\_rate} = \text{((Actual\_Lds*0.47)+Find\_gap\_rate\_Pol)*Pol\_fraction} \qquad (8)$$
$$\text{Find\_gap\_rate\_Pol} = \text{if(Real\_Pol}\leq8)\text{then(Gap\_Pol*0.1)else if(Real\_Pol}\leq24)$$
$$\text{then(Gap\_Pol*0.2)else if(Real\_Pol}\leq52)\text{then(Gap\_Pol*0.35)}$$
$$\text{else if(Real\_Pol}\leq60)\text{then(Gap\_Pol*0.1)else if(Real\_Pol}\leq80)$$
$$\text{then(Gap\_Pol*0.25)else (Gap\_Pol*0.25)} \qquad (9)$$
$$\text{Actual\_Pol} = \text{if(Real\_Pol}\leq8)\text{then(Real\_Pol)else if(Real\_Pol}\leq24)\text{then}$$
$$\text{(Real\_Pol-8)else if(Real\_Pol}\leq52)\text{then(Real\_Pol-24)else if}$$
$$\text{(Real\_Pol}\leq60)\text{then(Real\_Pol-52)else if(Real\_Pol}\leq80)\text{then}$$
$$\text{(Real\_Pol-60)else(Real\_Pol-60)} \qquad (10)$$

The increased 'Pol_rate' increased the Pol stock, as well as 'Real_Pol' and 'Actual_Pol' values. The 'Actual_Pol' value was then transferred to the Ppl and Rsr dynamic models.

People Dynamic Model

Ppl dynamic model illustrated that the 'Actual_Lds' and the 'Actual_Pol' values affected the 'Ppl_rate', as represented in Equations 11 to 14.

$$Ppl(t) = Ppl(t-dt)+(Ppl\_rate)*dt \tag{11}$$

$$Ppl\_rate = ((Actual\_Lds*0.25)+(Actual\_Pol*0.55)+Find\_gap\_rate\_Ppl)$$
$$*Ppl\_fraction \tag{12}$$

$$Find\_gap\_rate\_Ppl = if(Real\_Ppl<=9)then(Gap\_Ppl*0.1)else\ if(Real\_Ppl<=27)then$$
$$(Gap\_Ppl*0.2)else\ if(Real\_Ppl<=59)then(Gap\_Ppl*0.35)else\ if$$
$$(Real\_Ppl<=68)then(Gap\_Ppl*0.1)else\ if(Real\_Ppl<=90)then$$
$$(Gap\_Ppl*0.25)else(Gap\_Ppl*0.25) \tag{13}$$

$$Actual\_Ppl = if(Real\_Ppl<=9)then(Real\_Ppl)else\ if(Real\_Ppl<=27)then(Real\_Ppl-9)$$
$$else\ if(Real\_Ppl<=59)then(Real\_Ppl-27)else\ if(Real\_Ppl<=68)$$
$$then(Real\_Ppl-59)else\ if(Real\_Ppl<=90)then(Real\_Ppl-68)$$
$$else(Real\_Pp-68) \tag{14}$$

The 'Actual_Lds' value, shown in Equation 12, was multiplied by the constant value of 0.25, which was derived from the adjusted path coefficient from Lds to Ppl (0.49/(0.49+0.91+0.54), see Figure 1). The 'Actual_Pol' value was, on the other hand, multiplied by the constant value of 0.55, which was derived from the adjusted path coefficient from Pol to Ppl (0.41/(0.41+0.33). The 'Real_Ppl' scores, shown in Equations 13 and 14, were divided to match with the five maturity levels (i.e. 9, 27, 59, 68, and 90 points, respectively). The 'Gap_Ppl' was multiplied by constant values of 0.1, 0.2, 0.35, 0.1, and 0.25, respectively.

The 'Actual_Ppl' influenced the 'Actual_Ppl' value, which was then transferred to the Pro dynamic model.

Resources Dynamic Model

Lds and Pol had direct effects on Rsr, accordingly, the 'Actual_Lds' and 'Actual_Pol' values flew into the 'Rsr_rate', as shown in Equations 15 to 18. The increased 'Rsr_rate' value enhanced the 'Real_Rsr', as well as 'Actual_Rsr' values, and this, in turn, increased the 'Pro_rate' of the Pro dynamic model.

The 'Actual_Lds' value, shown in Equation 16, was multiplied by the constant value of 0.28, which was derived from the adjusted path coefficient from Lds to Rsr (0.54/(0.49+0.91+0.54), see Figure 1). The 'Actual_Pol' value was, on the other hand, multiplied by the constant value of 0.45, which was derived from the adjusted path coefficient from Pol to Rsr (0.33/(0.41+0.33). The 'Real_Rsr' scores were divided into five ranges to match with the five maturity levels (i.e. 9, 27, 59, 68, and 90 points, respectively).

$$Rsr(t) = Rsr(t-dt)+(Rsr\_rate)*dt \tag{15}$$

$$Rsr\_rate = ((Actual\_Lds*0.28)+(Actual\_Pol*0.45)+Find\_gap\_rate\_Rsr)$$
$$*Rsr\_fraction \tag{16}$$

$$Find\_gap\_rate\_Rsr = if(Real\_Rsr<=9)then(Gap\_Rsr*0.1)else\ if(Real\_Rsr<=27)$$
$$then(Gap\_Rsr*0.2)else\ if(Real\_Rsr<=59)then(Gap\_Rsr*0.35)$$
$$else\ if(Real\_Rsr<=68)then(Gap\_Rsr*0.1)else\ if(Real\_Rsr<=90)$$
$$then(Gap\_Rsr*0.25)else(Gap\_Rsr*0.25) \tag{17}$$

$$Actual\_Rsr = if(Real\_Rsr<=9)then(Real\_Rsr)else\ if(Real\_Rsr<=27)then(Real\_Rsr-9)$$
$$else\ if(Real\_Rsr<=59)then(Real\_Rsr-27)else\ if(Real\_Rsr<=68)$$
$$then(Real\_Rsr-59)else\ if(Real\_Rsr<=90)then(Real\_Rsr-68)$$
$$else(Real\_Rsr-68) \tag{18}$$

Processes Dynamic Model

Pro dynamic model demonstrated that the increased 'Actual_Ppl' and 'Actual_Rsr' values tended to increase the 'Pro_rate', see Equations 19 to 22. The 'Actual_Ppl' value was

multiplied by the constant value of 0.56, which was derived from the adjusted path coefficient from Ppl to Pro (0.53/(0.53+0.42), see Figure 1). The 'Actual_Rsr' value was, on the other hand, multiplied by the constant value of 0.44, which was derived from the adjusted path coefficient from Rsr to Pro (0.42/(0.53+0.42). The 'Real_Pro' scores were divided into five ranges to match with the five maturity levels (i.e. 14, 42, 91, 105, and 140 points, respectively).

$$Pro(t) = Pro(t-dt)+(Pro\_rate)*dt \qquad (19)$$

$$Pro\_rate = (Actual\_Ppl*0.56)+(Actual\_Rsr*0.42)+Find\_gap\_rate\_Pro \qquad (20)$$

$$\begin{aligned}Find\_gap\_rate\_Pro = \ &if(Real\_Pro<=14)then(Gap\_Pro*0.1)else\ if(Real\_Pro<=42)\\ &then(Gap\_Pro*0.2)else\ if(Real\_Pro<=91)then(Gap\_Pro*0.35)\\ &else\ if(Real\_Pro<=105)then(Gap\_Pro*0.1)else\ if(Real\_Pro<=140)\\ &then(Gap\_Pro*0.25)else(Gap\_Pro*0.25) \qquad (21)\end{aligned}$$

$$\begin{aligned}Actual\_Pro = \ &if(Real\_Pro<=14)then(Real\_Pro)else\ if(Real\_Pro<=42)then\\ &(Real\_Pro-14)else\ if(Real\_Pro<=91)then(Real\_Pro-42)else\\ &if(Real\_Pro<=105)then(Real\_Pro-91)else\ if(Real\_Pro<=140)then\\ &(Real\_Pro-105)else(Real\_Pro-105) \qquad (22)\end{aligned}$$

The increased 'Pro_rate' improved the 'Actual_Pro' value, which, ultimately, enhanced the 'Csr_rate' and 'Kpr_rate'.

Customer Results Dynamic Model

Pro appeared to be strongly correlated to Csr (with path coefficient of 0.85, see Figure 1). The increase or decrease of the 'Actual_Pro' value had an effect on the 'Csr_rate', as explained in Equations 23 to 25. The increased 'Csr_rate' value improved the 'Real_Csr' and 'Actual_Csr' values, which, in turn, influenced the 'Lds_rate' of the Lds dynamic model.

$$Csr(t) = Csr(t-dt)+(Csr\_rate)*dt \qquad (23)$$

$$Csr\_rate = Actual\_Pro*0.70 \qquad (24)$$

$$\begin{aligned}Actual\_Csr = \ &if(Real\_Csr<=29)then(Real\_Csr)else\ if(Real\_Csr<=86)then\\ &(Real\_Csr-29)else\ if(Real\_Csr<=186)then(Real\_Csr-86)else\\ &if(Real\_Csr<=214)then(Real\_Csr-186)else\ if(Real\_Csr<=285)then\\ &(Real\_Csr-214)else(Real\_Csr-214) \qquad (25)\end{aligned}$$

The 'Actual_Pro' value, shown in Equation 24, was multiplied by the constant value of 0.70, which was derived from the adjusted path coefficient from Pro to Csr (0.85/(0.85+0.36). The 'Real_Csr' scores were also divided into five ranges to match with the five maturity levels (i.e. 29, 86, 186, 214, and 285 points, respectively).

Key Performance Results Dynamic Model

Kpr was influenced by Pro and Csr dynamic models. The increase or decrease of the 'Actual_Pro' and 'Actual_Csr' values had the effects on the 'Kpr_rate', as explained in Equations 26 and 27. The 'Actual_Pro' value was multiplied by the constant value of 0.30, which was derived from the adjusted path coefficient from Pro to Kpr (0.36/(0.85+0.36)). The 'Actual_Csr' value was, on the other hand, multiplied by the constant value of 0.39, which represented the path coefficient from Csr to Kpr.

The increased 'Kpr_rate' value raised the 'Real_Kpr' value. This, as a result, improved the 'Lds_rate' of the Lds dynamic model.

$$Kpr(t) = Kpr(t-dt)+(Kpr\_rate)*dt \qquad (26)$$

Kpr_rate $=$ (Actual_Pro*0.30)+(Actual_Csr*0.39)   (27)

The simulations of the ergonomics culture dynamic model iterated as cycles, from the Lds to the Kpr dynamic models. In each cycle, the total ergonomics score was calculated, as illustrated in Equation 28, indicating the level of ergonomics maturity.
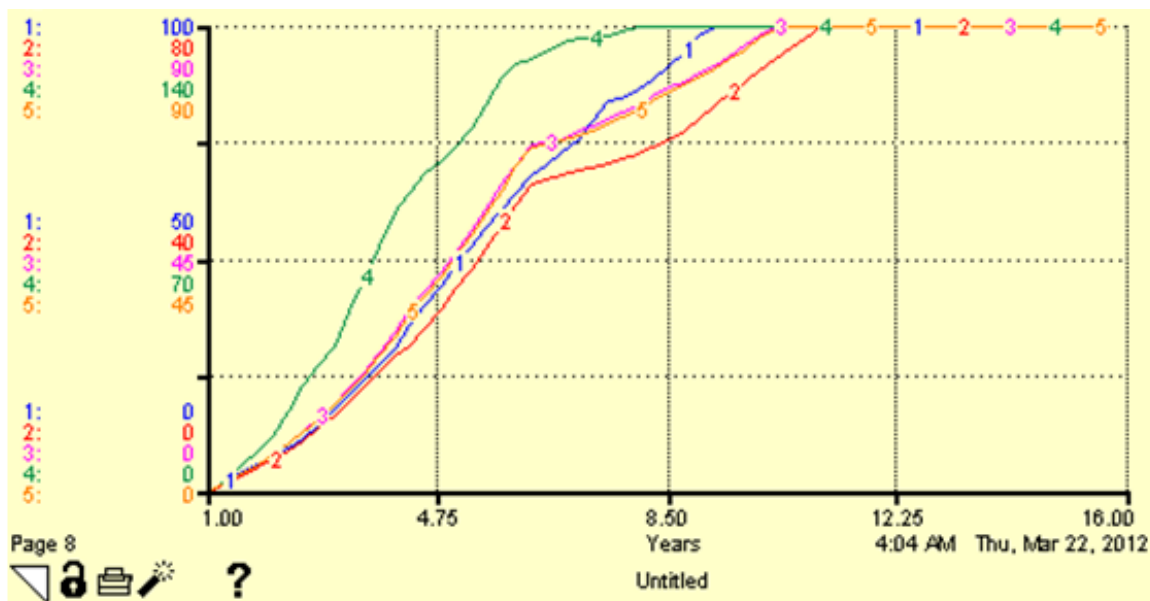
Total ergonomics score = Real_Lds+Real_Pol+Real_Ppl+Real_Rsr+Real_Pro+
$$\text{Real\_Csr+Real\_Kpr} \qquad (28)$$

The cycles continued until the total ergonomics score reached a maximum score of 1,000 points. The next section described the simulation results of the dynamic model of ergonomics culture.

Dynamic Simulation Results

The ergonomics dynamic model was simulated to examine the influences among the five 'enablers' and two 'results' over time. The initial scores of the seven factors were set to zero to imply the organization with no ergonomics implementation before. The results, as shown in Figures 3 and 4, revealed that the increased of the five 'enablers' scores increases the 'results' score, as well as the 'total ergonomics score'.

The organization progressed from level 1 to level 2 in one year, and proceeded to the fifth maturity level at the end of year 8 (see Table 1).

Note: 1 = Real_Lds 2 = Real_Pol 3 = Real_Ppl 4 = Real_Pro 5 = Real_Rsr

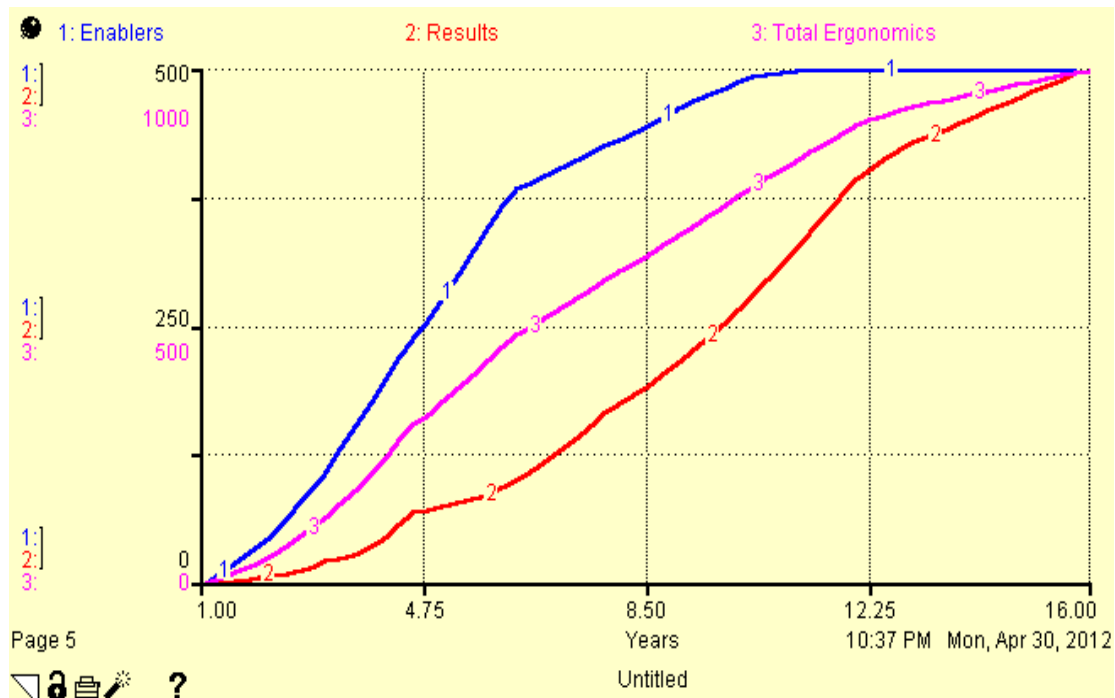Figure 3. Graphical results of the scores of the five enablers over time

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Figure 4. Graphical Results of the 'Enablers', 'Results', and 'Total Ergonomics' Scores

Table 1. Simulation Results of the 'Enablers', 'Results' and 'Total Ergonomics' Scores

Year	Enablers	Results	Total	Level
Initial	0.00	0.00	0.00	1st
1	41.19	5.75	46.95	1st
2	106.09	20.87	126.96	2nd
3	196.92	43.31	240.23	2nd
4	277.70	73.55	351.24	3rd
5	367.14	91.55	458.69	3rd
6	405.14	129.02	534.17	3rd
7	433.07	174.57	607.64	3rd
8	462.95	215.39	678.34	4th
9	488.52	265.74	754.25	5th
10	499.84	325.55	825.39	5th
11	500.00	394.83	894.83	5th
12	500.00	429.99	929.99	5th
13	500.00	454.58	954.58	5th
14	500.00	479.17	979.17	5th
15	500.00	500.00	1,000.00	5th

Model Validation: The Sensitivity Analysis

To validate the ergonomics dynamic model, a sensitivity analysis was conducted to test the robustness of the model, by ensuring that the uncertainties and the estimating errors do not significantly affect the overall behavior of the model (Forrester and Senge, 1980).
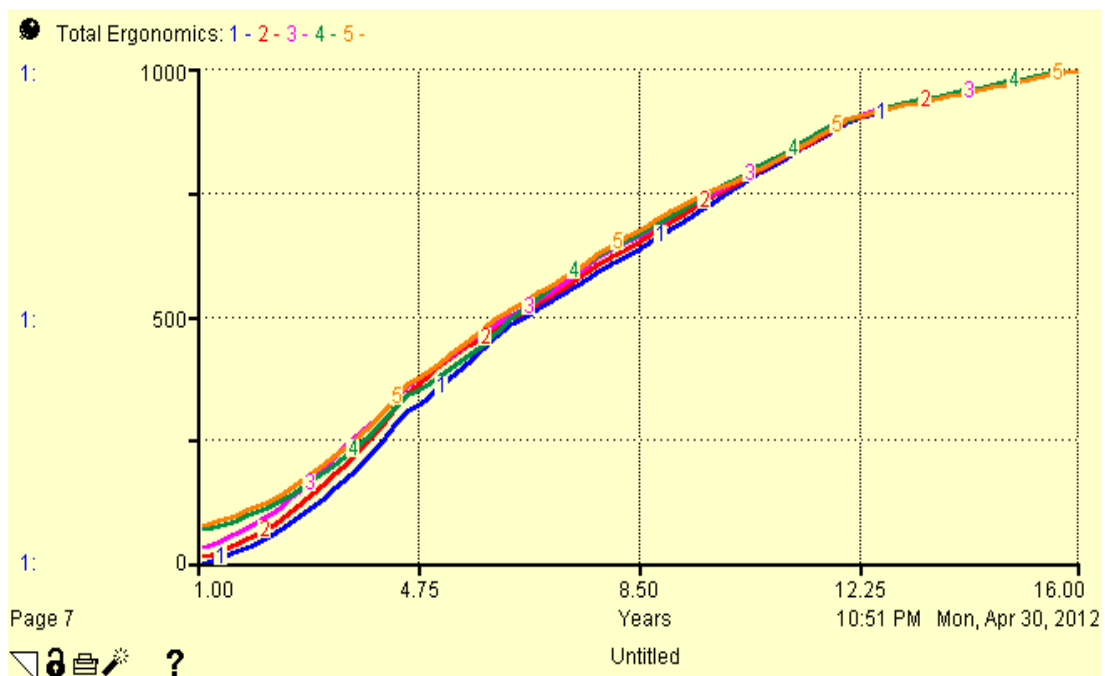
The sensitivity analysis of the ergonomics dynamic model was performed with the five 'enablers' by changing the initial value of the Lds, Pol, Ppl, Rsr, and Pro factors. For example, the initial values of the Lds factor were altered from zero to 11, 31, 66, and 76 points, respectively. The simulation results, displayed graphically in Figures 5 and 6,

demonstrated that the change in the initial values of the Lds factor only numerically affected the model behavior, not the pattern of the model, thus validating the model.
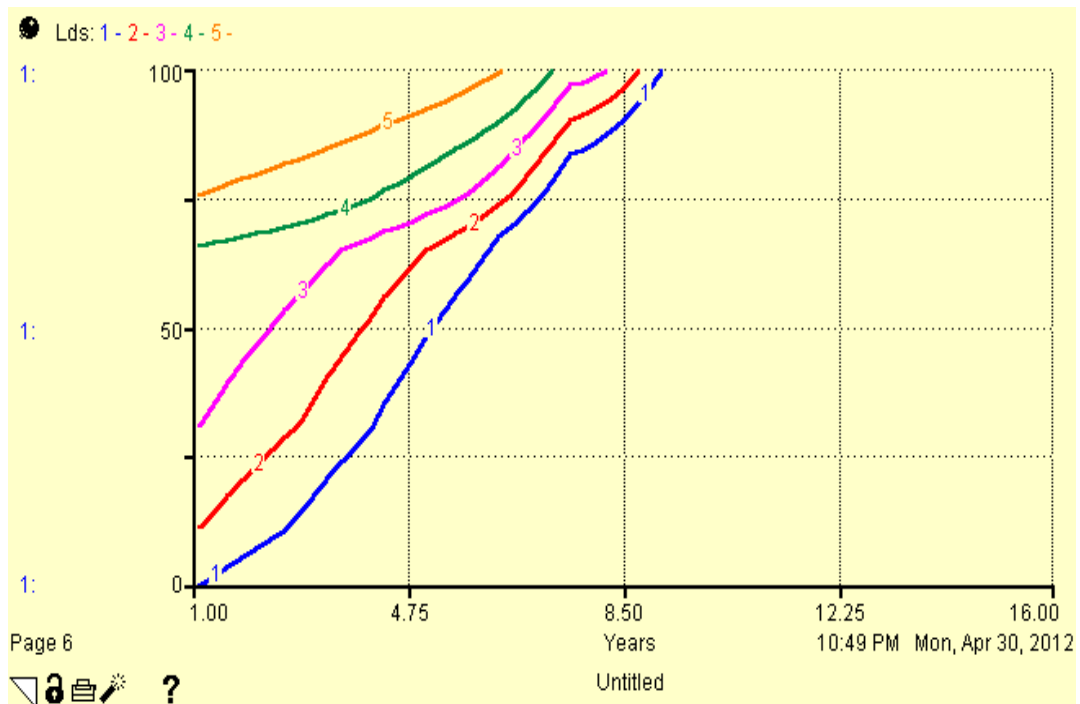
Note: The numbers 1, 2, 3, 4 and 5 represent the initial values of Lds of zero, 11, 31, 66, and 76 points, respectively.

Figure 5. Sensitivity Analysis Results of the Leadership when Its Initial Values are Changed

Note: The numbers 1, 2, 3, 4 and 5 represent the initial values of Lds of zero, 11, 31, 66, and 76 points, respectively.

Figure 6. Sensitivity Analysis Results of the 'Total Ergonomics' Scores when the Initial Values of the Leadership Factor are Changed

Conclusion

Ergonomics culture is a key to improving customer satisfaction and financial performance. Better understanding of the interactions among the key ergonomics 'enablers' and 'results' assist the organization to effectively plan for ergonomics improvement. In this paper, an ergonomics dynamic model was developed to investigate the relationships among the seven ergonomics factors. The 'total ergonomics' score was used to measure the current maturity level of ergonomics culture. The simulation results revealed that an organization with no ergonomics implementation before spent eight years to progress from level 1 to level 5, and the organization reached the maximum score of 1,000 points in 15 years. The organization can plan for ergonomics improvement by focusing on improving the scores of the five 'enablers' to achieve higher maturity levels. For example, leaders should be a role model in creating a positive ergonomics culture and provide adequate resources necessary for an effective ergonomics implementation.

Acknowledgement

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