P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol.26 No.2 April - June 2021
Page: [99-113]
Original research article

Effect of Management Attention on Ergonomics Culture Maturity: System Dynamics Modeling Approach

Thanwadee Chinda*

School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani 12120, Thailand

Received 3 March 2020; Received in revised form 27 November 2020
Accepted 4 March 2021; Available online 25 June 2021

ABSTRACT

Poor ergonomics culture is one of the major causes of accidents and injuries in the manufacturing industry. Improving the ergonomics culture assists organizations in reducing the incident rates, leading to better work performance, lower compensation costs, and higher productivity. Top management commitment is crucial in enhancing ergonomics culture in the company. Without management attention on ergonomics culture implementation, the ergonomics culture maturity may never be achieved. This paper, therefore, develops a dynamics model of ergonomics culture maturity, utilizing the system dynamics approach, to capture the interactions among key enablers and results, namely Leadership, Policy and Strategy, People, Resources, Processes, Customer, and Key Performance over time. The ergonomics culture maturity levels, developed through the dynamics model, are used to assess an organization's current level of ergonomics culture maturity, and plan for long term improvement. The management commitment to, and attention withdrawal from, ergonomics culture implementation are also examined through model simulations to examine the ergonomics culture maturity in the long-term.

Keywords: Ergonomics culture; Management attention; Maturity level; System dynamics modelling

1. Introduction

Ergonomics is defined as the study of the design of a workplace, equipment, machine, tool, product, environment, and system which takes into consideration human being's physical, physiological, biomechanical, and psychological capabilities [1-2]. It optimizes the effectiveness and productivity of work systems, while assuring the safety, health, and wellbeing of the workers. It considers a worker's capabilities and limitations to ensure that tasks, equipment, information, and environment suit the worker. To assess

***Corresponding author:** thanwadee@siit.tu.ac.th **doi:** 10.14456/scitechasia.2021.29

the fit between a person and his/her work, ergonomists consider jobs being done; demands on a worker; equipment used, including sizes, shapes, and how appropriate it is for tasks; and information used, including how it is presented, accessed, and changed. Nanthavanij [3] stated that the objectives of ergonomics are to maximize human contributions to system performance, and minimize system impacts on humans.

Ergonomics concepts have been applied in many industries, such as health care, oil, manufacturing, agricultural industry, and product design. Salleh and Sukadarin [2], for example, differentiated the terms human factor and ergonomics in pineapple plantations, and concluded that the human factor and ergonomics need different approaches to be tackled and managed in the workplace setting. Shikdar [4] examined the ergonomic problems affecting worker productivity and health and safety on Oman oilrigs under hot climatic conditions. They concluded that ergonomics is needed in work system design to reduce health and safety problems. Kumar et al. [5] applied a participatory ergonomics method to identify cleaning problems, and suggested an improved working posture to reduce work-related musculoskeletal disorders and discomfort. Yaoyuenyong and Nanthavanij [6] developed two heuristic job rotation procedures for industrial workers, and determined the sets of worker- job- period assignments to prevent safety hazards in workplaces.

There are many ways to apply sustainable ergonomics in a manufacturing environment. One approach that addresses ergonomics at all levels of an organization is an ergonomics culture [7-8]. The ergonomics and ergonomics culture concept is applied in researches in various areas in Thailand. Wang [9] studied the correlation between ergonomics and office syndrome in the workplace in Thailand, and suggested that having the proper equipment increases productivity and employee engagement, leading to the reduction of direct and indirect costs and improvement of quality and safety standard of the company. Samrong [10] examined influences of ergonomic and psychosocial risk factors on the stress of computer operators in an office at the Headquarters of Airports of Thailand Public Company Limited, and concluded that the ergonomic and the psychosocial risk factors positively correlated with the stress of the operators on computers in an office. Polyong et al. [11] studied causes of upper musculoskeletal disorder of students who carry bags beyond the proportion of standard body weight, and mentioned that the overweight school bag affects deformation of bones or chronic back pain symptoms. Chinda et al. [12] developed an ergonomics culture dynamic model to capture the interactions among key ergonomics factors and identify areas for ergonomics culture improvement in Thailand.

The ergonomics culture considers five key enablers, namely Leadership, Policy and Strategy, People, Resources, and Processes. All of these five enablers affect ergonomics culture results, in terms of customer satisfaction and key performance [12]. Chinda et al. [12] stated that the interrelationships among key enablers and results are dynamic, and are crucial for organizations to effectively plan for their ergonomics culture improvement in the long-term. In real practices, however, top management sometimes withdraws attention from ergonomics culture implementation to other areas of improvement, resulting in poor ergonomics culture in the company. The organization, therefore, needs to be able to assess its current ergonomics culture maturity level, so that the improvement plan can be established to progress through to higher levels of maturity in the long-term.

This paper, hence, develops the dynamics model of ergonomics culture maturity to capture dynamics interactions among key enablers and results, and examine the effects of management attention on

ergonomics culture maturity. It is expected that the developed dynamics model will assist organizations to effectively plan for ergonomics culture improvement in the long-term. The research steps of this study are shown in Fig. 1.

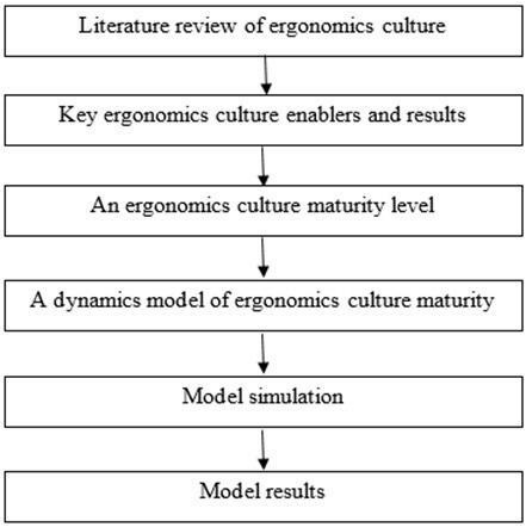

Fig. 1. Research steps of this study.

2. Materials and Methods

2.1 Key enablers and results of ergonomics culture

Chinda et al. [12] developed an ergonomics culture model based on two widely used international quality models, including the European Foundation for Quality Management Excellence and Total Quality Management models. It consists of five key enablers, namely Leadership (Lds), Policy and Strategy (Pol), People (Ppl), Resources (Rsr), and Processes (Pro), to achieve two major results, which are Customer (Csr) and Key Performance (Kpr) results.

- Leadership: This enabler represents how top management develops and facilitates the achievement of an ergonomics culture vision, develops values required for long-term success, and is personally involved to ensure that an ergonomics culture system is developed and maintained.
- Policy and Strategy: This enabler supports relevant policies, plans, objectives, targets, and processes. To successfully implement an ergonomics culture program, an organization must provide its vision via clear focused strategies.
- People: This enabler supports ergonomics culture policies. An organization needs to manage, develop, and release ergonomics knowledge, from individual to organization-wide levels.
- Resources: This enabler refers to how an organization plans and manages resources to support its ergonomics culture policies, people, and effective operations of its processes.
- Processes: This enabler refers to how an organization designs, manages, and improves its processes to support its ergonomics culture policies, people, and resources.
- Customer: This result refers to the achievements of an organization in relation to its external customers, related to ergonomics culture matters, such as better work quality and higher customer satisfaction.
- Key Performance: This result is defined as what an organization achieves in terms of financial performance from an ergonomics culture implementation.

The enablers and results of the ergonomics culture model interact with each other, forming cause-and-effect relationships. Chinda and Rittippant [13] examined the interrelationships among key enabler and results in a large-sized manufacturing company, with almost 1500 staff, located in Rayong Province, Thailan. It is a global enterprise with core competencies in the life science fields of health care and agriculture. Major businesses in Thailand are under its divisions of pharmaceuticals, consumer health, and crop science. The company has a total of nine departments, in which they involve with activities that can

cause ergonomic-related problems, such as lifting, bending, pushing, and repetitive work. This results in high compensation costs, leaves, and turnover rate in the company.

By utilizing the structural equation modeling approach, Chinda and Rittippant [13] summarized the causal relationships among the seven constructs (five enablers and two results), as well as the degree of influence the constructs have on each other (see Fig. 2). The Leadership enabler, for example, has strong influences on the Policy and Strategy, Resources, and People enablers, with the degrees of influences of 0.91, 0.54, and 0.49, respectively (maximum influence is 1), The improvement of the Leadership enabler will enhance the implementation of the Policy and Strategy, Resources, and People enablers. Top management plays an important role in setting up ergonomics culture policies and strategies, assigning employee responsibilities, and providing ergonomics-related resources to support ergonomics culture implementation.

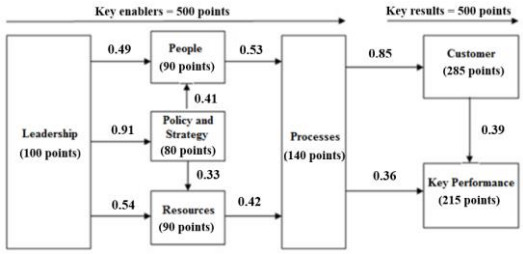

Fig. 2. Proposed ergonomics culture model [12-13].

The implementation of the People and Resources enablers directly affect the implementation of Processes enabler, while the Policy and Strategy enabler indirectly influences the Processes enabler through the People and Resources enablers. Proper implementation of the Processes enabler results in better customer and performance results (with the degrees of influences of 0.85 and 0. 36, respectively). This is consistent with Wilson and Collier [14] that good ergonomics policies and strategies assist employees in acquiring necessary resources, to implement an ergonomics culture program. With good ergonomics culture implementation, higher customer satisfaction and better work performance can be achieved.

2.2 Criterion weight of the ergonomics culture constructs

Apart from the causal links among key ergonomics culture constructs, criterion weight is an important part of an ergonomics culture model. EFQM [15], for example, equally divided a maximum of 1,000 points into enablers and results. Gargalianos and Matsaridis [16] also considered maximum points of enablers and results as 500 points each in the evaluation of total quality management in the sport industry. Liu and Ko [14], on the other hand, utilized the 450 points for the enablers and 550 points for the results to evaluate the performance in the hotel industry.

In this study, a total ergonomics culture score of 1000 points is evenly split (500/500) between the key enablers and results, as shown in Fig. 2. The 500 points allocated to the five enablers are distributed as 100, 80, 90, 90, and 140 points to the Leadership, Policy and Strategy, People, Resources, and Processes enablers, respectively. This is consistent with EFQM [15] and Gargalianos and Matsaridis [16]. The 500 points of the results are, on the other hand, split into 285 and 215 points for the Customer and Key Performance results, respectively [12, 17].

At any point in time, the summed score of the seven constructs is called the total ergonomics culture score, and ranges from a minimum of zero to a maximum of 1,000 points.

2.3 Ergonomics culture maturity levels

The total ergonomics culture score is used to assess the current level of ergonomics culture maturity of an organization. Different

researches propose different maturity levels with various score- ranges. Shehata et al. [18], for example, developed a quantitative assessment tool for process safety performance by implementing a proposed capability maturity framework, and divided the maturity into four levels, in which each level has the score-range of 250 points. EFQM [15], in contrast, divided the total score of 1,000 points into five levels: uncommitted level having the scores from 0 to 249 points, drifters level having the scores from 250 to 499 points, improvers level having the scores from 500 to 749 points, award winners level having the scores from 750 to 999 points, and world-class level having the score of 1,000 points. Dale and Smith [19] divided the total of 1,000 points into six levels with the score- ranges of 100, 100, 100, 350, 100, and 250 points, respectively. Ahmed et al. [20] interviewed senior managers and consultants, and distributed the 1,000 points into seven levels: uncommitted level having the scores from 0 to 149 points, drifter level having the scores from 150 to 299 points, tool pusher level having the scores from 300 to 499 points, improver level having the scores from 500 to 649 points, award winner level having the scores from 650 to 849 points, world-class level having the scores from 850 to 999 points, and superlative level having the score of 1,000 points.

In view of the score-range diversity, this study utilizes five levels of ergonomics culture maturity [12-19], as shown in Fig. 3.

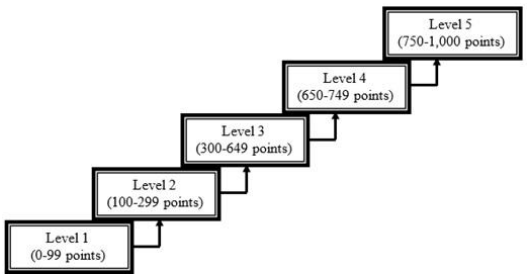

Fig. 3. Ergonomics culture maturity levels [12-19].

- Level 1: This level ranges from 0 to 99 points. At this level, an ergonomics culture is not given priority in terms of either managerial time or resource allocation.
- Level 2: This level is from 100 to 299 points. At this level, an organization is concerned with an ergonomics culture, and has more operating experiences for ergonomics culture implementation.
- Level 3: This level ranges from 300 to 649 points. An organization is engaged in a process of continuous improvement.
- Level 4: This level ranges from 650 to 749 points. At this level, an organization has reached a point that its ergonomics culture maturity is a business success.
- Level 5: This level is 750 to 1000 points. At this final level, an ergonomics culture is a core company value that is continuously improving at all operating levels.

The seven ergonomics culture constructs, together with ergonomics culture maturity levels, are used to develop the dynamics model of ergonomics culture maturity.

2.4 Management attention on ergonomics culture

In real-life situations, the total ergonomics culture score may never reach its maximum score of 1000 points (see Fig. 3). This is due to top management's view of level 5 for maturity as a target, and not for continual improvement. Once the top level of maturity is reached, top management withdraws the drive behind all ergonomics cultural activities. This is consistent with NPS Risk Management Division [21] that considered the accident cycle, where top management gradually and slowly withdrew its attention to safety when safety performance reflected the highest level of maturity.

The assumption made in the modeling process is that top management withdraws its

ergonomics culture attention when the total ergonomics culture score reaches 950 points. This represents high confidence in an organization's ergonomics culture development ability [22]. At this point, top management may gradually shift its ergonomics attention to other areas for improvement, believing that an adequate ergonomics culture development system is in place, and effective implementation of this system will continue, regardless of the level of management attention. This attention withdrawal reduces the Leadership score, resulting in a lower total ergonomics culture score. This continues until the total ergonomics culture score reaches its lowest limit, which in this study is at 300 points (i.e. the lowest point of level 3 of ergonomics culture maturity). Falling into level 2 of maturity, the top management improves the ergonomics culture again by, for example, providing more ergonomic-related resources, empowering employees with appropriate ergonomics- related responsibilities, and providing feedback on ergonomics matters. As a result, the total ergonomics culture score increases, and the cycle repeats. Nevertheless, a maximum score of 1000 points can be achieved in the long term through repeated cycles of ergonomics culture implementation. This is due to continuous improvement in ergonomics culture implementation.

2.5 System dynamics modeling approach

Due to the complexity of the relationships among key enablers and results in enhancing the ergonomics culture in the company, this study utilizes the system dynamics (SD) modeling technique to develop the dynamics model of ergonomics culture maturity. Moreover, as management attention on ergonomics culture fluctuates through time, there is a need to examine this effect in a dynamics environment through the developed dynamics model.

The SD modeling approach is used for modeling the behavior of complex social systems, examining interrelationships between variables, and simulating how model elements interact over time [23-24]. It has been applied to a wide variety of disciplines, such as business, safety, construction performance, health, profit enhancement, and waste management. Nasirzadeh et al. [25], for example, utilized an SD methodology to examine the risks of bridge construction project performance, where time, cost, and quality are crucial. Mohamed and Chinda [26] developed a construction safety culture model to plan for effective safety implementation in the construction industry in Thailand. The SD modeling approach was also used to predict waste generation, collection, and disposal, and assess the budget needed for waste management in Delhi, India [27]. Nguyen and Chinda [28] utilized the SD modeling approach to examine the profit of residential projects in Ho Chi Minh city, Vietnam, in the long term.

In this study, the dynamic model of ergonomics culture maturity is developed using the STELLA software package. The model consists of five major components, including stock, flow, converter, cloud, and connector, as shown in Fig. 4 and Table 1.

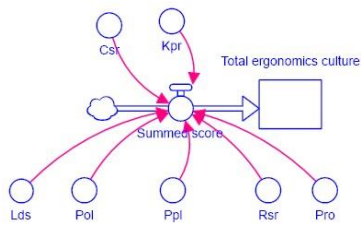

Fig. 4. Components of the dynamics model using the STELLA software.

3. Results and Discussion

3.1 Dynamics model of ergonomics culture maturity

The dynamics model of ergonomics culture maturity is developed to capture the interactions among five enablers and two results, and their effects, as well as the effect of management attention withdrawal, on

ergonomics culture maturity levels over time. Data used in the dynamics model development are listed in Table 2. Details of each sub-model are as follows.

Table 1. Descriptions of the dynamics model components.

Symbol	Name	Description
Stock	Stock	A stock is defined as a structural term for anything that accumulates, for example, savings in the bank.
Flow	Flow	If stocks are bathtubs, then flows are pipes that feed and drain them.
leadership	Converter	If stocks are names of structure and flows are verbs, then converters are adjectives and adverbs.
	Cloud	A cloud is an infinite reservoir representing the map boundary. The capacity of cloud is so great that it makes no sense to worry about filling or draining it.
	Connector	A connector is used to link the sectors and converters to other converters

3.1.1 Leadership Sub-model

At the beginning of ergonomics culture implementation, the top management pays attention to improve the total ergonomics culture score. This results in an increase in the Leadership stock (*Lds (t)*) and Leadership rate (*Lds rate*), as shown in Eqs. (1) and (2). Once the total ergonomics culture score reaches 950 points (the fifth level of maturity), the inflow of the Leadership stock becomes zero ("*Lds rate*" = 0), representing the attention withdrawal from top management.

$$Lds(t) = Lds(t - dt) + (Lds\ rate - out\ LDS) \times dt, \quad (1)$$

$$Lds(t) = If\ (Total > D\ Total)$$
$$\text{or } \big((300 < Total < D\ Total) \text{ and } (slope < 0)\big)$$
$$Then\ (0)\ Else\ (Adj\ rate), \quad (2)$$

where $Lds(t) =$ Leadership stock,

$Lds(t - dt) =$ Leadership stock in the last period,

$Lds\ rate =$ Leadership rate,

$Out\ Lds =$ Outflow of Leadership score,

$Total =$ Total ergonomics culture score,

$D\ Total =$ Maximum total ergonomics culture score when management attention withdrawal occurs i.e. 950 points,

$Slope =$ Slope of total ergonomics culture score,

$Adj\ rate =$ Leadership rate based on the influence of the result scores on the Leadership model.

Table 2. Data used in the dynamics model development.

Construct	Data	Reference
Leadership	• Upper limit of total ergonomics culture score when management attention withdrawal occurs: 950 points • Lower limit of total ergonomics culture score when management attention withdrawal occurs: 300 points • Maximum Leadership score: 100 points	[13, 15, 21-22]
Policy and Strategy	• Maximum Policy and Strategy score: 80 points • Adjusted influence from Leadership to Policy and Strategy enablers: 0.47 • Effect of management attention withdrawal on Policy and Strategy enabler: 0.16	[13, 15, 21-22, 29]
People	• Maximum People score: 90 points • Adjusted influence from Leadership to People enablers: 0.25 • Adjusted influence from Policy and Strategy to People enablers: 0.55 • Effect of management attention withdrawal on People enabler: 0.18	[13, 15, 21-22, 29-30]
Resources	• Maximum Resources score: 90 points • Adjusted influence from Leadership to Resources enablers: 0.28 • Adjusted influence from Policy and Strategy to Resources enablers: 0.45 • Effect of management attention withdrawal on Resources enabler: 0.18	[13, 15, 21-22, 30-31]
Processes	• Maximum Processes score: 140 points • Adjusted influence from People to Processes enablers: 0.53 • Adjusted influence from Resources to Processes enablers: 0.42	[13, 15, 30, 32]
Customer	• Maximum Customer score: 285 points • Adjusted influence from Processes enabler to Customer result: 0.7	[13, 15, 33]
Key Performance	• Maximum Key Performance score: 215 points • Adjusted influence from Processes enabler to Key Performance result: 0.3 • Adjusted influence from Customer to Key Performance results: 0.39	[13, 15, 32-33]

The "*Adj rate*" in Eq. (2) is calculated based on the influence of the result scores on the Leadership model. The result scores, received from the Customer and Key Performance sub-models (with 500 points maximum; see Fig. 2), reflect the attention that top management has on an ergonomics culture implementation. When the result score is low, top management pays attention to improve the ergonomics culture implementation, resulting in an increase in the Leadership score.

As the attention to ergonomics gets withdrawn from top management, an outflow of the Leadership stock increases ("*Out Lds*"

> 0) ; see Eq. (3). The total ergonomics culture score continues to drop until it reaches the lower limit of 300 points. Then, top management reacts to increase this total score again.

$$Out\ Lds = If\ (Lds\ rate > 0)\ or\ \left((300 < Total < D\ Total)\ and\ (Slope > 0)\right)\ or\ (Total < 300)\ Then(0)\ Else(Ldsr\ ate \times 0.2). \quad (3)$$

The Leadership stock is compared with its maximum score (100 points, see Fig. 2) to achieve the actual leadership score (*Actual Lds*), see Eq. (4). This score is used to calculate the total ergonomics culture score.

$$Actual\ Lds = Max(Lds(t), 100). \quad (4)$$

The Leadership sub-model directly affects the People, Policy and Strategy, and Resources sub-models, as seen from the path coefficients among the Leadership and three other enablers (see Fig. 2). A high or low Leadership score affects the scores of the three connected sub- models. This, in turn, influences the ergonomics culture implementation (i.e., the Processes sub-model), and the results (i.e., the Customer and Key Performance sub-models).

3.1.2 Policy and strategy sub-model

Top management influences the establishment of ergonomics culture policies and strategies in an organization. This can be seen from the flow of the Leadership score to the "Pol rate", see Eqs. (5) and (6).

$$Pol(t) = Pol(t - dt) + (Pol\ rate - Out\ Pol) \times dt, \quad (5)$$

$$Pol\ rate = If\ (Lds\ rate > 0)\ Then\left(\left(Actual\ Lds \times 0.47\right) + In\ Pol\right) Else(0), \quad (6)$$

where $Pol(t)$ = Policy and Strategy stock,

$Pol(t - dt)$ = Policy and Strategy stock in the last period,

$Pol\ rate$ = Policy and Strategy rate,

$Out\ Pol$ = Outflow of Policy and Strategy score,

$Lds\ rate$ = Leadership rate,

$Actual\ Lds$ = Actual Leadership score,

$In\ Pol$ = Inflow of Policy and Strategy score.

In Eq. (6), the "*Actual Lds*" value is multiplied by a constant value of 0.47 that is derived from the adjusted path coefficient from the Leadership to Policy enablers. This is done by normalizing the total influence the Leadership has on the other three enablers (i.e., 0.49, 0.91, and 0.54, see Fig. 2) to 1. Therefore, the influence the Leadership has on the Policy enablers is

$$\frac{0.91}{(0.49 + 0.91 + 0.54)} = 0.47.$$

When top management withdraws its attention from ergonomics culture implementation, there tends to be a decrease in the focus of ergonomics policy and strategy. This, in turn, reduces the Policy and Strategy score or increases the Policy and Strategy outflow ("*Out Pol*" > 0), see Eq. (7).

$$Out\ Pol = If\ (Out\ rate > 0)\ Then(In\ Pol \times 0.16)\ Else(0) \quad (7)$$

When the scores of the Policy and Strategy and Leadership enablers decrease, the score of the People sub-model decreases, as these two enablers influence this sub-model (see Fig. 2).

3.1.3 People sub-model

In the People sub-model, an increase or decrease of "*Actual Lds*" and "*Actual Pol*" values affect the "*Ppl rate*"; see Eqs. (8) and (9). The "*Actual Lds*" value is multiplied by a constant value of 0.25 that is derived from the normalizing value of $0.49 / (0.49 + 0.91 + 0.54)$. The "*Actual Pol*"

value is, on the other hand, multiplied by a constant value of 0.55 that is derived from $0.41/(0.41+0.33)$, see Fig. 2.

$$Ppl(t) = Ppl(t-dt) + (Ppl\ rate - Out\ Ppl) \times dt, \quad (8)$$

$$Ppl\ rate = If\ (Lds\ rate > 0) Then((Actual\ Lds \times 0.25) + (Actual\ Pol \times 0.55) + In\ Ppl)\ Else(0), \quad (9)$$

where $Ppl(t) =$ People stock,
$Ppl(t-dt) =$ People stock in the last period,
$Ppl\ rate =$ People rate,
$Out\ Ppl =$ Outflow of People score,
$Lds\ rate =$ Leadership rate,
$Actual\ Lds =$ Actual Leadership score,
$Actual\ Pol =$ Actual Policy and Strategy score,
$In\ Ppl =$ Inflow of People score.

When top management withdraws its attention from the ergonomics culture implementation ("*Out Lds*" > 0), employees focus less on ergonomics activities, resulting in a lower People score ("*Out Ppl*" > 0), see Eq. (10). The changes in the People score affect the Processes sub-model, as seen from the strong path coefficient between these two enablers.

$$Out\ Ppl = f\ (Out\ Lds > 0) Then(In\ Ppl \times 0.18)\ Else(0). \quad (10)$$

3.1.4 Resources sub-model

The Leadership and Policy and Strategy enablers directly affect the Resources enabler. Accordingly, the "*Actual Lds*" and "*Actual Pol*" values flow into the "*Rsr rate*", see Eqs. (11) and (12). The "*Out Rsr*" (see Eq. 13) represents the reduction of the Resources score when top management withdraws its attention from ergonomics culture implementation, and provides insufficient resources ("*Out Lds*" > 0).

$$Rsr\ rate = Rsr(t-dt) + (Rsr\ rate - Out\ Rsr) \times dt, \quad (11)$$

$$Rsr\ rate = If\ (Lds\ rate > 0) Then((Actual\ Lds \times 0.28) + (Actual\ Pol \times 0.45))\ Else(0), \quad (12)$$

$$Out\ Rsr = If\ (Out\ Lds > 0) Then(In\ Rsr \times 0.18)\ Else(0), \quad (13)$$

where $Rsr(t) =$ Resources stock,
$Rsr(t-dt) =$ Resources stock in the last period,
$Rsr\ rate =$ Resources rate,
$Out\ Rsr =$ Outflow of Resources score,
$Lds\ rate =$ Leadership rate,
$Actual\ Lds =$ Actual Leadership score,
$Actual\ Pol =$ Actual Policy and Strategy score,
$In\ Rsr =$ Inflow of Resources score.

An increased " *Rsr rate* " value enhances the Resources stock, as well as the "*Actual Rsr*" value. These, in turn, increase the "*Pro rate*" of the Processes sub-model.

3.1.5 Processes sub-model

A decrease of "*Actual Ppl*" and "*Actual Rsr*" scores lowers the "*Pro rate*" score, see Eqs. (14) and (15). Likewise, a decrease of the "*Actual Pro*" score negatively affects the Customer and Key Performance sub-models.

$$Pro(t) = Pro(t-dt) + (Pro\ rate - Out\ Pro) \times dt, \quad (14)$$

$$Pro\ rate = If\ (Lds\ rate > 0) Then((Actual\ Ppl \times 0.53) + (Actual\ Rsr \times 0.42) + In\ Pro)\ Else(0), \quad (15)$$

where $Pro(t) =$ Processes stock,
$Pro(t-dt) =$ Processes stock in the last period,
$Pro\ rate =$ Processes rate,
$Out\ Pro =$ Outflow of Processes score,

$Lds\ rate =$ Leadership rate,
$Actual\ Ppl =$ Actual People score,
$Actual\ Rsr =$ Actual Resources score,
$In\ Pro =$ Inflow of Processes score.

3.1.6 Customer sub-model

An increase or decrease in the "*Actual Pro*" value affects the "*Csr rate*", as shown in Eqs. (16) and (17). An increased "Csr rate" value improves the " Actual Csr" value, which consequently increases the "Kps rate" of the Key Performance sub-model.

$$Csr(t) = Csr(t - dt) + (Csr\ rate - Out\ Csr) \times dt, \quad (16)$$

$$Csr\ rate = If\ (Lds\ rate > 0)\ Then(Actual\ Pro \times 0.7)\ Else(0), \quad (17)$$

where $Csr(t) =$ Customer stock,
$Csr(t - dt) =$ Customer stock in the last period,
$Csr\ rate =$ Customer rate,
$Out\ Csr =$ Outflow of Customer score,
$Lds\ rate =$ Leadership rate,
$Actual\ Pro =$ Actual Processes score.

3.1.7 Key performance sub-model

The Key Performance sub- model is influenced by the Processes and Customer sub- models, see Eqs. (18) and (19). An increased "*Kpr rate*" value raises the total ergonomics culture score and increases the "*Lds rate*" in the Leadership sub-model.

$$Kpr(t) = Kpr(t - dt) + (Kpr\ rate - Out\ Kpr) \times dt, \quad (18)$$

$$Kpr\ rate = If\ (Lds\ rate > 0)\ Then(Actual\ Pro \times 0.3) + (Actual\ Csr \times 0.39)\ Else(0), \quad (19)$$

where $Kpr(t) =$ Key Performance stock,
$Kpr(t - dt) =$ Key Performance stock in the last period,
$Kpr\ rate =$ Key Performance rate,
$Out\ Kpr =$ Outflow of Key Performance score,
$Lds\ rate =$ Leadership rate,
$Actual\ Pro =$ Actual Processes score,
$Actual\ Csr =$ Actual Customer score.

An increased result score from the Customer and Key Performance sub- models raises the total ergonomics culture score, thus, encouraging continuous improvement.

3.1.8 Total ergonomics culture sub-model

The scores of five enablers and two results are summed to represent the total ergonomics culture score, as shown in Eq. (20). This total score shows the level of ergonomics culture maturity of an organization.

$$Total\ Ergonomis = Actual\_Lds + Actual\_Pol + Actual\_Ppl + Actual\_Rsr + Actual\_Pro + Actual\_Csr + Actual\_Kpr, \quad (20)$$

where $Total\ Ergonomis =$ Total ergonomics culture score,
$Actual\_Lds =$ Actual Leadership score,
$Actual\_Pol =$ Actual Policy and Strategy score,
$Actual\_Ppl =$ Actual People score,
$Actual\_Rsr =$ Actual Resources score,
$Actual\_Pro =$ Actual Processes score,
$Actual\_Csr =$ Actual Customer score,
$Actual\_Kpr =$ Actual Key Performance score.

The simulation of the dynamics model of ergonomics culture maturity, including five enablers and two results, iterates as cycles between levels 3 and 5 of ergonomics culture maturity. This iteration continues until the total ergonomics culture score

reaches its maximum score of 1000 points in the long term.

3.2 Simulation results

The dynamics model of ergonomics culture maturity is simulated with initial values of five enablers and two results of zero. This reflects the situation that an organization never implements ergonomics culture activities. Simulation results, as illustrated in Table 3 and Figs. 5-7, show that at the beginning of the ergonomics culture implementation, the total ergonomics culture score is low, representing level 1 of maturity. When the implementation continues, the total score increases, ascending from level 1 to level 5 of maturity.

At the end of year 15, the five enablers reach the maximum score of 500 points, while the score of the two results is 450.32 points, leading to the total ergonomic score of 950.32 points. This is over the upper limit (950 points); as a result, the top management starts to unintentionally withdraw its ergonomics culture attention. This, consequently, drops the scores of five key enablers (see Fig. 5), resulting in reduced result (see Fig. 6) and total ergonomics culture scores (see Fig. 7). This is consistent with NPS Risk Management Division [21] that top management gradually and slowly withdraws its attention to safety when safety performance reflects the highest level of maturity.

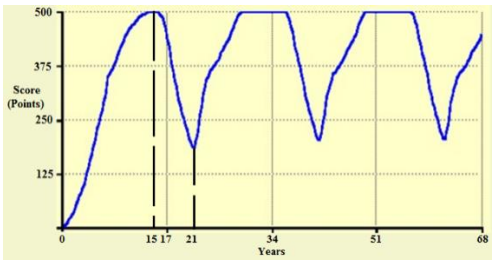

Fig. 5. Graphical results of the five enablers score.

Table 3. Simulation results of the five enablers, two results, and total ergonomics culture scores.

Year	Score								Maturity
	Lds	Pol	Ppl	Res	Pro	Csr	Kpr	Total	Level
Initial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
1	3.56	2.62	3.40	3.36	7.97	1.95	0.95	23.79	1
2	7.45	6.12	8.31	8.08	20.73	7.83	5.17	63.69	1
3	12.77	10.96	15.17	14.80	35.95	16.83	12.98	119.46	2
4	21.64	16.40	22.52	21.94	57.23	27.17	25.87	192.77	2
5	28.93	23.67	34.30	32.51	79.43	44.77	37.41	281.02	2
6	43.52	30.74	43.77	41.89	96.85	67.27	57.10	381.15	3
7	61.57	40.74	55.44	53.40	115.76	70.87	73.99	471.78	3
8	68.24	46.78	64.93	62.65	126.52	83.05	96.74	548.90	3
9	78.92	51.05	74.32	70.40	130.86	99.52	110.34	615.41	3
10	97.11	54.47	78.53	74.28	137.19	119.15	126.56	687.31	4
11	100.00	60.98	84.20	80.02	140.00	143.11	152.86	761.17	5
12	100.00	67.68	89.51	85.49	140.00	167.70	188.81	839.19	5
13	100.00	74.38	90.00	90.00	140.00	192.29	215.00	901.67	5
14	100.00	80.00	90.00	90.00	140.00	216.88	215.00	931.88	5
15	100.00	80.00	90.00	90.00	140.00	235.32	215.00	950.32	5
16	100.00	73.14	90.00	90.00	140.00	175.08	201.55	869.77	5
17	100.00	62.12	80.03	76.01	122.64	130.27	161.59	732.65	4
18	88.87	52.76	66.56	63.22	91.74	96.93	129.55	589.63	3
19	72.39	44.81	55.37	52.59	68.63	72.12	103.86	469.76	3
20	58.96	38.06	46.05	43.74	51.34	53.66	83.27	375.08	3
21	48.02	32.33	38.31	36.38	38.40	39.92	66.76	300.12	3
22	52.76	35.75	42.38	40.50	45.63	45.53	68.67	331.22	3
23	68.02	47.38	57.42	55.13	78.85	56.40	80.53	443.73	3
24	76.76	51.78	68.07	65.08	96.24	72.29	101.30	531.51	3
25	84.91	53.65	71.48	68.04	100.65	76.95	120.53	576.21	3
26	99.61	57.63	74.91	71.51	103.48	84.32	143.12	634.59	3
27	100.00	64.31	80.42	77.15	110.74	89.78	151.40	673.80	4
28	100.00	71.01	86.91	83.58	123.31	96.81	156.59	718.20	4
29	100.00	77.71	90.00	90.00	140.00	114.34	170.32	782.37	5
30	100.00	80.00	90.00	90.00	140.00	138.93	195.19	834.12	5
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
229	**100.00**	**80.00**	**90.00**	**90.00**	**140.00**	**285.00**	**215.00**	**1000.00**	**5**

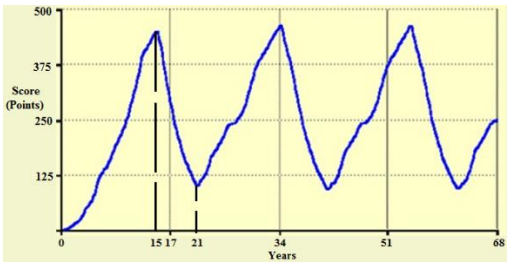

Fig. 6. Graphical results of the two results score.

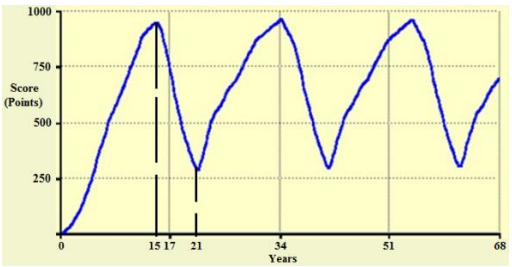

Fig. 7. Graphical results of the total ergonomics culture score.

The total ergonomics culture score continues to decrease until it reaches its specified lower limit of 300 points at the end of year 21 (see Table 3). At that stage, the score of five enablers drops to 193.44 points (see Fig. 5), representing no effort in implementing the ergonomics culture in the company. This, in turn, decreases the two results score to 106.68 points (see Fig. 6). Top management must, then, take prompt actions to improve the ergonomics culture implementation, fearing that the organization will drop to the lowest level of maturity. As a result, an increase in the Leadership score enhances the implementation of the Policy and Strategy, People, Resources, and Processes enablers, leading to higher Customer and Key Performance scores, and ultimately, an increased total ergonomics culture score. This action continues until the total ergonomics score exceeds the specified upper limit of 950 points. Then, the attention withdrawal takes place again, and the cycle continues.

The simulation results show that the total ergonomics culture score oscillates between levels 3 and 5 for the ergonomics culture maturity. However, it slowly ascends toward a maximum score of 1000 points over a long period of time (see Table 3 and Fig. 8).

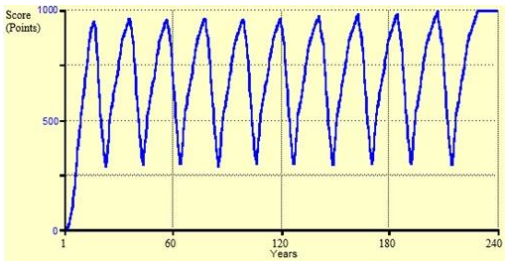

Fig. 8. Long-term results of the total ergonomics culture score.

3.3 Model verification and validation

The dynamics model of ergonomics culture maturity is tested with two important processes: model verification and model validation, to establish confidence in the soundness and usefulness of the dynamics model. There are various tests that may be conducted in the process of verifying a model. Such tests include logical, extreme-value, and mass-balance tests [34].

- Logical tests are designed to assure the parametric verification, dimensional integrity, and unit consistency, correct sequence of calculation, and stochastic/statistical character.
- Extreme-value tests are designed to assure stability under exposure to extreme conditions and extreme policies.
- Mass-balance tests are designed to assure that physical flows do not violate the basic requirement for physical flows into a model to either accumulate or flow out. Mass-balance must be assured during every time-step of every simulation run.

A model is considered behaviourally validated if simulation results display similar behavioural patterns when compared with observed behaviour in a real system. According to Forrester and Senge [35], the focus of validating activities are on three types of tests: model structure, model behaviour, and policy implications.

In this study, the logical test had been used for model verification to assure parametric verification, unit consistency, and correct sequence of calculation. The five enablers and two results are confirmed by a number of previous studies [15-23] The year-time unit is consistently used throughout the simulation. The sequence of the calculation is correct, following the directional influences shown in Figs. 2 and 3. The model is also considered behaviourally validated as the simulation results display similar behavioural patterns compared with observed behaviour in a real system, such as that studied by NPS Risk Management Division [21].

4. Conclusions

Ergonomics culture is becoming an important issue for the health and safety of

workers, as it helps in designing jobs, equipment, and workplaces to fit workers, and helps to reduce long-term disability. Ergonomics culture is important for improving customer satisfaction and financial performance. This study develops a dynamics model of ergonomics culture maturity to examine the relationships among five key ergonomics culture enablers and two results, to assess the levels of ergonomics culture maturity of an organization over time.

The developed dynamics model shows that top management is a key aspect in establishing an ergonomics culture in an organization. Encouragement from top management improves the scores of the five enablers, including the Leadership, Policy and Strategy, People, Resources, and Processes. These, in turn, enhance the Customer and Key Performance results, and the total ergonomics culture score, leading to a higher level of ergonomics culture maturity.

In real life situations, however, top management withdraws its attention from ergonomics culture implementation when the fifth level of maturity is achieved. This decreased Leadership score negatively affects the other four enablers, two results, and ultimately the total ergonomics culture scores. This continues until the total ergonomics culture score reaches its lower limit, that is, an organization falls into the second maturity level. At this stage, the top management intercedes to improve the score by, for example, promoting ergonomics culture campaigns, assigning appropriate ergonomics culture responsibilities, and providing necessary resources to effectively implement ergonomics culture activities. This approach continues until the total ergonomics score surpasses its upper limit. Then, the attention withdrawal starts again, and the cycle continues. As a result, the total ergonomics score oscillates between levels 3 and 5 of the ergonomics culture maturity. However, an organization can ascend toward a maximum score of 1000 points over a long period of time.

An organization can use the developed dynamics model to test alternative strategies, through a number of model simulations, to improve ergonomics culture and achieve higher levels of ergonomics culture maturity. Such strategies are, for example, setting different lower and upper limits, adjusting the initial scores of the five enablers and two results, and modifying the score ranges of the ergonomics culture maturity levels to reflect an organization's real practices.

This study contributes to the body of knowledge in many ways.

- The dynamics model of ergonomics culture maturity explores the causal relationships among the five key enablers and two results necessary to create a mature environment in an organization.
- The ergonomics culture maturity levels developed in this study assist an organization to better understand its level of maturity, and plan for ergonomics culture improvement. Organizations with different maturity levels will need different policies and implementation processes, which cannot be imitated.
- This study simplifies the examination of relationships among enablers and results in a user- friendly graphical format, utilizing a system dynamics modeling approach.
- The developed dynamics model facilitates the testing of alternative strategies through model simulations to improve ergonomics culture. This saves time by not having to implement ineffective strategies. This may also help an organization to save costs that it incurs by not implementing the best strategy.

Such contributions provide a strong foundation for understanding the ergonomics culture of an organization. Data used in this study are, however, from companies and literature review in Thailand. Data, such as maximum score of each key criterion and

score- ranges of the ergonomics culture maturity levels, could be adjusted.

Acknowledgements

The author would like to thank Mr. Chaiwat Manasakunkit for his help in this research study.

References

[1] Fernandez JE, Marley RM. Applied occupational ergonomics: a textbook. 4th ed. Fairfax, VA: Society for Industrial and Systems Engineering Press; 2014.

[2] Salleh NFM, Sukadarin EH. Defining human factor and ergonomic and its related issues in Malaysia pineapple plantations. MATEC Web of Conferences 2018:150:1-8.

[3] Nanthavanij S. Ergonomic work posture for safe working with notebook computer. Workshop for Ergonomic Work Posture for Safe Working with Notebook Computer. Pathumthani, Thailand: School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University; 2010.

[4] Shikdar AA. Identification of ergonomic issues that affect workers in oilrigs in desert environments. Int J Occup Saf Ergon 2004:10(2):169-77.

[5] Kumar R, Chaikumarn M, Lundberg J. Participatory ergonomics and an evaluation of a low- cost improvement effect on cleaners' working posture. Int J Occup Saf Ergon 2005:11(2):203-10.

[6] Yaoyuenyong S, Nanthavanij S. Heuristic job rotation procedures for reducing daily exposure to occupational hazards. Int J Occup Saf Ergon 2008:14(2):195-206.

[7] Lee KS. Ergonomics in total quality management: how can we sell ergonomics to management? Ergon 2002: 48(5) : 47-558.

[8] McDonald I, Zairi M, Idris MD. Sustaining and transferring excellence: a framework of best practice of TQM transformation based on winners of Baldrige and European Quality Awards. Meas Bus Excel 2002:6(3):20-30.

[9] Wang PS. Happiness in the workplace: the effects of ergonomics on office syndrome (Master Thesis). Pathumthani, Thailand: Thammasat University; 2016.

[10] Samrong A. The influence of ergonomic and psychosocial risk factors on the stress of computer operators in an office. PSAKU Int J Interdisciplinary Res 2018:7(1):22-30.

[11] Polyong CP, Sarapimpha N, Deekla C, Phukkarawek S, Thepthong B, Poldongnok P. Effects of upper musculoskeletal disorder from school bag usage among primary school grade 4- 6 students for a school in Bangkok metropolis. J Department Medical Serv 2019:44(4):1-6.

[12] Chinda T, Manasakunkit C, Hongpinyo W, Suethrong T. System dynamics approach to an ergonomics model. Proc 3rd Int Conf Eng Proj Prod Manag, September 10- 11, 2012. Brighton, United Kingdom 2012:119-30.

[13] Chinda T, Rittippant N. Implementing company- wide ergonomic knowledge and culture and improving office and plant at Bayer Material Science. (in Thai). Report to APACT Project. Rayong, Thailand: Bayer Thai Co., Ltd.; 2010.

[14] Wilson DD, Collier DA. An empirical investigation of the Malcolm Baldrige National Quality Award causal model. Decision Sci 2000:31(2):361-90.

[15] EFQM. Introducing excellence. Brussels, Belgium: The European Foundation for Quality Management; 2000.

[16] Gargalianos D, Matsaridis A. Evaluation of the total quality management maturity of the Hellenic National Sport Federations using the EFQM model. J Phys Educ Sport 2017:17(2):675-9.

[17] Liu YL, Ko PF. A modified EFQM Excellence model for effective evaluation in the hotel industry. Tot Qual Manag 2018:29(13):1580-93.

[18] Shehataa WM, Farounb HA, Gada FK, Bhrana AA. A quantitative assessment tool for process safety performance by implementing a proposed capability maturity framework. Int J Saf Sci 2019:3(1):173-88.

[19] Dale BG, Smith M. Spectrum of quality management implementation grid: development and use. Manag Serv Qual 1997:7(6):307-11.

[20] Ahmed AM, Yang JB, Dale BG. Self-assessment methodology: the route to business excellence. Qual Manag J 2003:10(1):43-57.

[21] NPS Risk Management Division. Occupational Safety and Health Overview for NPS Employees [Internet]. 2006 [cited 2020 Oct 15] . Available from: https://www.nps.gov/training/tel/Guides/OSH_emp_pguide_2006_0605.pdf

[22] Chinda T. Investigate the cyclical style of safety management utilizing the construction safety culture dynamic model. Proc 5th Int Conf Constr 21st Century, May 20- 22, 2009; Istanbul, Turkey; 2009.

[23] Wolstenholme EF. System enquiry: a system dynamic approach. New York, USA: John Wiley & Sons; 1994.

[24] Rodrigues AG, Bowers J. The role of system dynamics in project management. Int J Proj Manag 1996:14(4):213-20.

[25] Nasirzadeh F, Afshar A, Khanzadi A. system dynamics approach for construction risk analysis. Int J Civil Eng 2008:6(2):120-31.

[26] Mohamed S, Chinda T. System dynamics modelling of construction safety culture. Eng Constr Arch Manag 2011:18(3):266-81.

[27] Ahmad K. A system dynamic of municipal solid waste management systems in Delhi. Int J Res Eng Tech 2012:1(4):628-41.

[28] Nghia NH, Chinda T. Dynamic model of profit of residential projects in Ho Chi Minh City, Viet Nam. Int J Strat Property Manag 2018:22(6):489-500.

[29] Vigoda- Gadot E. Leadership style, organizational politics, and employees' performance: an empirical examination of two competing models. Personnel Rev 2007:36(5):661-83.

[30] Mankan W. A causal relationship of effectiveness in research policy implementation of Rajabhat University lecturers in the Northern region of Thailand. Local Admin J 2020:13(1):1-13.

[31] Zadeh SSM. The study of role of leadership styles and organizational culture on the financial performance (case study: Mellat bank' s branches in the Bushehr province. Int J Human Cultural Studies 2016:April:1459-68.

[32] Eldor L, Vigoda-Gadot E. The nature of employee engagement: rethinking the employee-organization relationship. Int J Human Resource Manag 2017:28(3):526-52.

[33] Cengiz E, Ayyildiz H, Er B. Effects of image and advertising efficiency on customer loyalty and antecedents of loyalty: Turkish banks sample. Banks Bank Sys 2007:2(1):56-71.

[34] McLucas AC. System dynamics applications: a modular approach to modelling complex world behaviour. Canberra, Australia: Argos Press; 2005.

[35] Forrester JW, Senge PM. Tests for building confidence in system dynamic models. TIMS Studies Manag Sci 1980:14:209-28.