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Investigate the Cyclical Style of Safety Management Utilizing the Construction Safety Culture Dynamic Model

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Abstract

The major cause of construction accidents is viewed as the direct result of having a poor safety culture. A better understanding of how to improve safety culture greatly assists an organization to allocate appropriate safety resources, and improve its safety performance. This paper develops a construction safety culture (CSC) dynamic model, based on a widely used EFQM Excellence model, to capture the interactions and causal relationships among the key enablers and goals of CSC, over a period of time. The CSC index, developed through the CSC dynamic model, is used to measure the current CSC maturity level of the organization. The cyclical style of safety management is also modeled, through the CSC dynamic model, to reflect the situations where management withdraws attention from safety, which then leads to a reduced CSC index.

Keywords

Construction safety culture dynamic model, Construction safety culture index, Cyclical style of safety management, Enablers, Goals

1. Introduction

The construction industry is different from the manufacturing industry due to its fragmented structure; its diffused responsibility; its prototype nature; its influences of public, regulatory agencies, and interest groups; its transient and itinerant labor force, which is not trained to operate under the quality assurance mode of construction; and its virtual lack of research and development (Jaafari, 1996). A construction project is a unique task, has a predetermined date of delivery, is subject to one or several performance goals, and consists of a number of complex activities. The projects may vary from simple dwellings to complex structures, and normally involve many changes, such as frequent teamwork rotations, exposure to weather conditions, and high rates of unskilled workers (Rosenfeld *et al.*, 2006).

Maloney (2003) stated that the construction industry is one of the most hazardous industries. Construction accidents cause many human tragedies, de-motivate workers, disrupt site activities, delay project progress, and adversely affect the overall cost, productivity, and reputation of the construction industry. According to Smith and Roth (1991), the main cause of construction accidents is the direct result of having a poor safety culture. Positive changes in safety in the construction industry will not be fully effective until safety culture is improved. A better understanding of safety culture will help construction organizations to strategically allocate safety resources, and thus improve their overall occupational health and safety performance on sites.

Recently, many research studies have been undertaken in the area of *construction safety culture* (*CSC*). A number of tools has been developed to measure CSC, and plan for CSC improvements. A major shortcoming with these tools, though, is the inability to appropriately capture and present causal links between what the organization is doing and what it aims to achieve (called the *Enablers* and *Goals*, respectively). Another element of weakness lies in a lack of understanding about the interactions among different CSC enablers, as well as the extent of their individual, or combined, effects on the organization's ability to achieve safety performance improvements. There has also been little examination of the extent to which there is a consensus among workers and managers regarding the contributions of the identified enablers in determining perceptions of safety culture. In other words, organizations should realistically assess their CSC maturity level, and progress sequentially through different levels of cultural maturity. This paper, thus, sets out to develop a CSC dynamic model, utilizing the system dynamics (SD) modeling, to simulate the interactions and causal relationships among the CSC enablers, and to predict the influence of each enabler on safety goals, over a period of time. The CSC index, developed through the SD simulation, is used to measure the current CSC maturity level of the organization. The cyclical style of safety management is also modeled to reflect real-life situations where management withdraws attention from safety, which then leads to a reduced CSC index.

2. CSC Dynamic Model

The SD modeling is used to develop the CSC dynamic model. It is a method for modeling and analyzing the behavior of complex social systems, particularly in an industrial context. It has been used to examine various social, economic, and environmental systems, where a holistic view is important, and feedback loops are critical to the understanding of the interrelationships (Rodrigues and Bowers, 1996). A SD simulation approach relies on an understanding of complex interrelationships existing among different elements within a system. This understanding is achieved by developing a model that can simulate and quantify the behavior of the system over time. Such simulations are considered essential in understanding the dynamics of the system. In the construction domain, many researchers have reported SD modeling applications. Love *et al.* (2000), for example, developed a SD model to capture the interrelationships among factors that contribute to design errors and reworks in construction projects. Tang and Ogunlana (2003) employed the SD methodology to provide a careful and holistic evaluation of the improvement policies to enhance organizational performance.

The CSC dynamic model is developed based on one of the most widely used quality management models, the European Foundation for Quality Management (EFQM) Excellence model. It is based on the logical assumption that by improving how the organization operates, there will be an inevitable improvement in the results. Empirical evidence suggests that the application the EFQM Excellence model has a positive effect on organizational performance (Kristensen and Juhl, 1999). The CSC dynamic model comprises six constructs, including five 'enablers' and a single set of *Goals* (see Figure 1). The five enablers are *Leadership (Lds)*, *Policy and Strategy (Pol)*, *People (Ppl)*, *Partnerships and Resources (Prs)*, and *Processes (Pro)*. It is assumed that leadership drives people management, policy and strategy, as well as resources, and that these three enablers collectively influence the ability to achieve pre-determined *Goals* through the implementation and improvement of suitable processes.

In addition to the enablers and *Goals*, the criterion weights are also an important part of the model. A total of 1,000 points of the CSC dynamic model is evenly split (500/500) between the enablers and *Goals*. 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 *Prs*, and 140 points to *Pro* (EFQM, 1998). Importantly, this allocation of points among enablers, reflecting their relative contribution to the achievement of *Goals*, is an area of much debate. For practical purposes, however, this study adopted the original enablers' allocation promoted by the EFQM Excellence model. These criterion weights are used to develop the CSC index to assess the organization's CSC maturity levels.

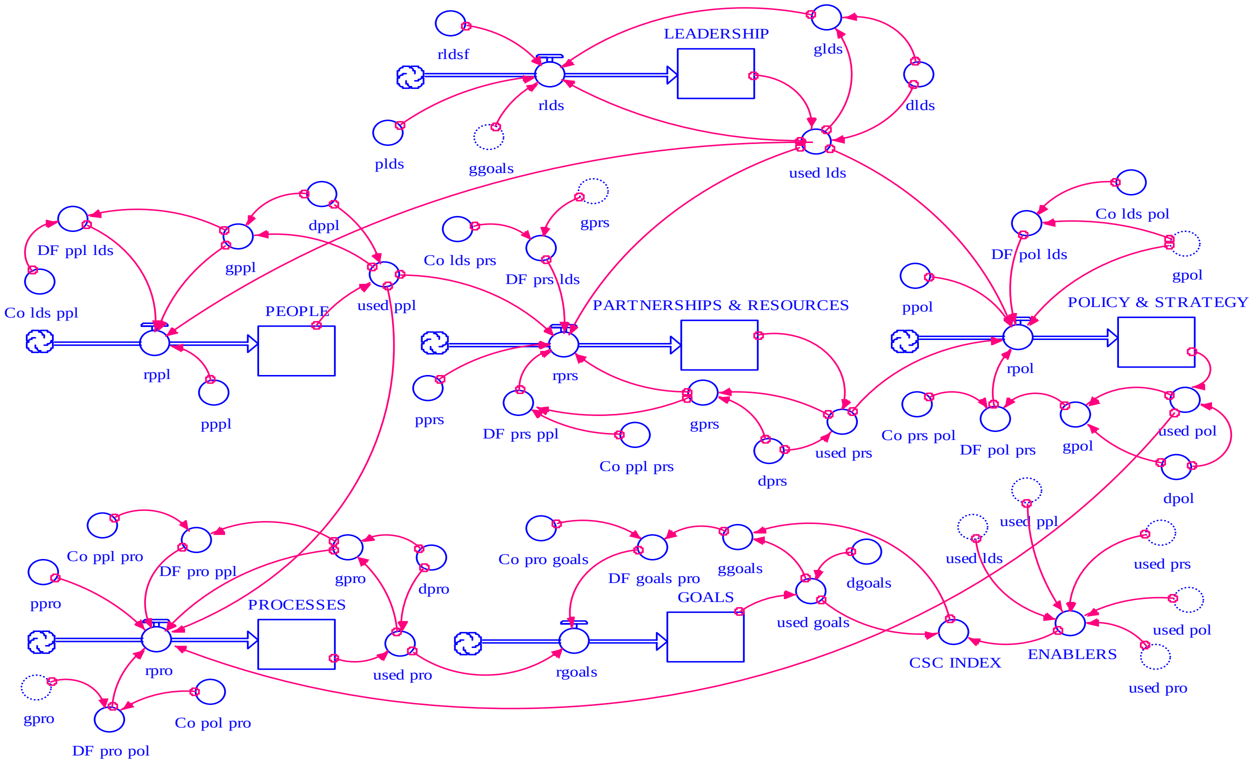

Figure 1: The CSC Dynamic Model

3. Causal Loop Diagram of CSC Dynamic Model

To conceptualize a real world system under investigation, the SD focuses on the structure and behavior (over time) of the system using multiple feedback loops. These feedback loops are presented graphically using a causal loop diagram. A loop is a closed system, comprising a number of elements and causal relationships. The arrows indicate the direction of influence, and plus/minus signs indicate the type of the influence (Khanna *et al.*, 2004). A causal link from 'A' to 'B' is positive if either 'A' adds to 'B' or a change in 'A' produces a change in 'B' in the same direction. On the other hand, a causal link from 'A' to 'B' is negative if either 'A' subtracts from 'B' or a change in 'A' produces a change in 'B' in the opposite direction. In addition to the signs on each link, the complete feedback loop also is given a sign. If a particular element starts the loop by changing its value in one direction (e.g. by increasing its value), and closes the loop with the value changed in the same direction (e.g. closes the loop by increasing the value), then the loop is called a positive loop. A negative loop is the reverse.

Figure 2 shows a causal loop diagram of the CSC dynamic model. The loop consists of seven elements to explain the relationships between the *Enablers*, *Goals*, and the CSC index. At any point of time, the *CSC index score* represents the sum of the *Enablers score* and the *Goals score*. This score is compared with the *Desired CSC index score*, resulting in a *Gap of CSC index* that reflects the difference between these two values. As the *CSC index score* increases (as a result of an improvement in the *Enablers score* and the *Goals score*), the *Gap of CSC index* decreases, forming a negative relationship. Following the continuous improvement cycle, the resulting decrease of the *Gap of CSC index* tends to increase the *Enablers score*. Thus, the relationship between the *Gap of CSC index* and the *Enablers score* is negative because a change in the *Gap of CSC index* results in a change in the opposite direction of the *Enablers score*. The increased *Enablers score*, undoubtedly, enhances the *CSC index score*, representing a positive relationship. This then closes a positive loop between the *CSC index score*, the *Gap of CSC index*, and the *Enablers score* (the loop starts and ends by increasing the *CSC index score*). Continuing with the

Enablers score, the increased *Enablers score* improves the *Goals score*. The higher *Goals score*, when compared with the *Desired Goals score* (which is set as 500 points), results in a smaller *Gap of Goals* (a negative relationship is formed). The perceived smaller goals gap will tend to enhance the implementation of the five enablers (the *Enablers score* increases). Therefore, the loop between the *Enablers score*, the *Goals score*, and the *Gap of Goals* is considered a positive loop, i.e. the loop starts and closes by increasing the *Enablers score*.

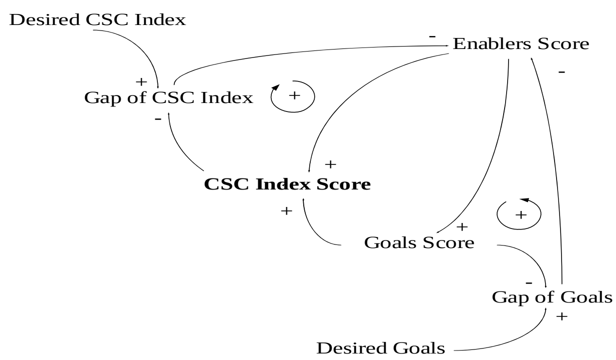

Figure 2: Causal Loop Diagram of CSC Dynamic Model

4. Dynamic Simulation Results

The CSC dynamic model is simulated, with the initial values of the five enablers set as zero to manipulate the situation of organizations with no prior safety implementation. The results are displayed in Figure 3, and Table 1. The five CSC maturity levels, shown in Table 1, are developed based on the capability maturity model (Lardner *et al.*, 2001) to assist organizations in establishing their current level of safety culture maturity, and in identifying actions required to improve their safety culture. Each maturity level has a score-range. According to the EFQM (1998), the total score of 1,000 points is divided into five levels, as follows: Levels 1 to 4 ranges from 0-249, 250-499, 500-749, and 750-999 points, respectively, and level 5 has a single score of 1,000 points.Many researchers, however, report the use of the EFQM Excellence model with a number of different levels and respective score ranges (Dale and Smith, 1997; Ahmed *et al.*, 2003). In this study, thus, the score-range for each maturity level is set as 200 points i.e. the score-ranges of levels 1 to 5 are 0-200, 201-400, 401-600, 601-800, and 801-1,000 points, respectively.

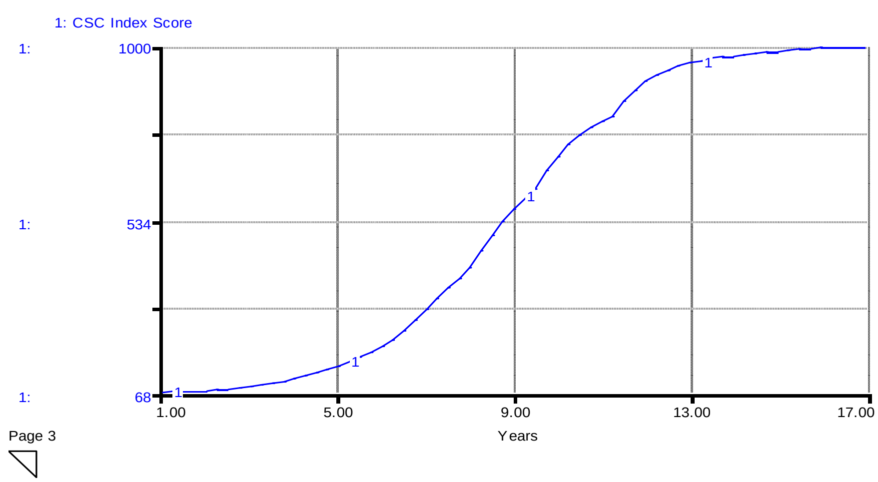

Figure 3: Graphical Results of the CSC Index over Time

Table 1: Simulation Results of the Enablers, Goals and CSC Index

Year	Enablers		Goals		CSC Index		Maturity Level
	Score	%Increasing	Score	%Increasing	Score	%Increasing	
Initial	0.00	-	68.00	-	68.00	-	1st
1	4.00	0.80	68.00	0.00	71.98	0.40	1st
2	14.01	2.00	68.13	0.03	82.14	1.02	1st
3	33.82	3.96	69.12	0.20	102.94	2.08	1st
4	66.57	6.55	72.08	0.59	138.65	3.57	1st
5	112.86	9.26	77.84	1.15	190.71	5.21	1st
6	175.90	12.61	114.61	7.35	290.52	9.98	2nd
7	246.21	14.06	156.79	8.44	403.00	11.25	3rd
8	317.30	14.22	244.71	17.58	562.01	15.90	3rd
9	375.24	11.59	329.25	16.91	704.49	14.25	4th
10	416.27	8.21	381.64	10.48	797.91	9.34	4th
11	**446.64**	6.07	**461.90**	16.05	**908.55**	11.06	**5th**

Note: Bold numbers refer to the time unit, where the organization reaches the fifth level of CSC maturity.

As shown in Table 1, at the starting point, the CSC index score is 68 points. At this stage, the gap of the *Goals* value is relatively large (500 – 68 = 432 points). This, then, boosts the value of *Lds*, which, in turn, increases the values of the remaining four enablers, i.e. *Ppl*, *Pol*, *Prs*, and *Pro*. As the five enablers' values increase (identifying an improvement in safety culture's implementations), the *Goals* value, and the CSC index increase. The simulation continues until the CSC index reaches the maximum score of 1,000 points i.e. the *Enablers* and *Goals* values reach their maximum 500 points. On this simulation, it takes 11 years for the organization, with a non-existent safety policy and safety implementation process, to progress from the first to the fifth levels of CSC maturity (the CSC index reached 800 points or more at the end of year 11). The graph shown in Figure 3 illustrates an S-shaped pattern, with a slow increase at the beginning of the simulation. It takes six years for the organization to progress from the first to the second levels of culture maturity. This demonstrates that for an organization with a non-existent safety culture policy and implementation process, it is hard to improve the CSC in the early stage of the safety implementation. This is shown by a slow increase in the rate for *Enablers*, and the even slower increased rate for *Goals*. After the organization reaches the second maturity level, however, the *Enablers* and *Goals* values increase rapidly, which in turn, enhance the CSC index, as depicted by the sharp rise in the curve. The organization progresses from the second to the fifth maturity levels over five years (at the end of year 11), showing a significant safety improvement in the organization. After year 11, it is difficult for the organization to increase the *Enablers* value, as most of the safety implementations are accomplished. Moreover, the extra effort needed to further improve safety in the organization might be switched to other important areas. This, in turn, slows the increase rate of the CSC index (see Figure 3). It appears to be very challenging to reach a perfect safety implementation; however, an organization can plan its safety implementation to progress through to the fifth CSC maturity level.

5. The Dynamic Model of the Cyclical Style of Safety Management

As mentioned, it is very difficult for the organizations to reach the maximum score of CSC index (1,000 points). One key reason is top management's view of the fifth maturity level as a target, not as means of continual improvement. Once the fifth maturity level is reached, top management tends to slow the momentum behind all safety activities. This phenomenon is known as '*attention withdrawal*', where top management gradually and slowly withdraws its attention to safety when safety performance reflects the highest level of maturity (NPS Risk Management Division, 2006). In this study, the cyclical style of safety management is modeled with SD modeling. The assumption made in the modeling process is that top management withdraws its attention to safety when the CSC index reaches 95% of its maximum score (950 points, representing the upper limit of management satisfaction with safety performance, see Figure 4). The 95% level is selected as it represents a very high confidence in the organization's safety management ability, and any accidents that might occur can be largely traced to random events represented by the 5% error level. At this point, top management starts gradually shifting its safety attention to other areas for improvement, believing that an adequate safety management system is in place, and the effective implementation of this system will continue, regardless of the level of management support/attention. Eighty percent of the maximum score of the CSC index, on the other hand, is chosen as the lower limit (800 points). At this point, the organization is falling into the lower maturity level, i.e. from the fifth to the fourth maturity levels. Top management realizes the problem, and starts taking actions to improve the CSC index.

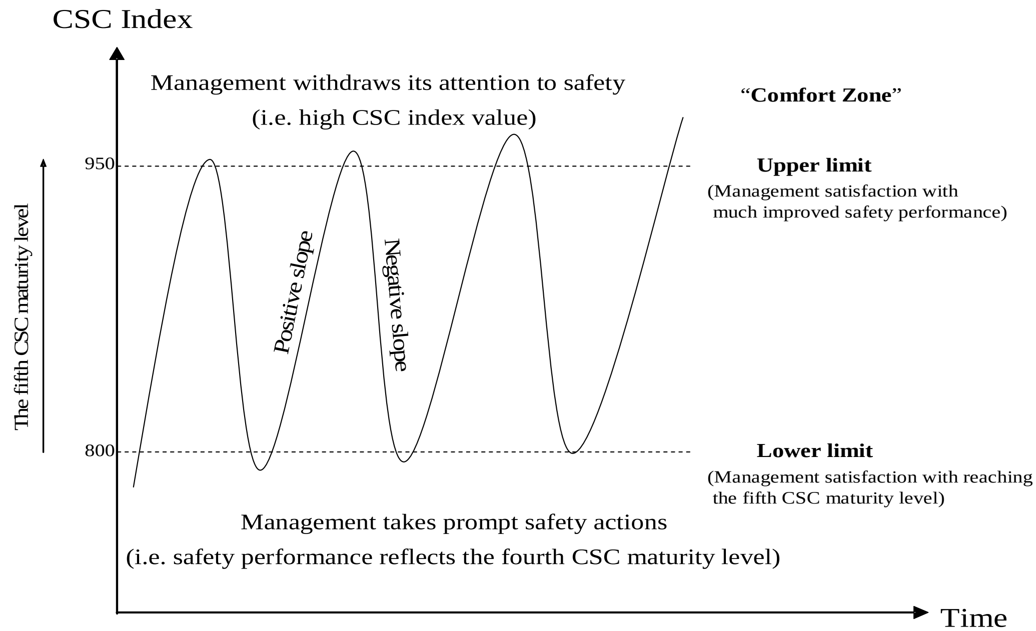

Figure 4: The CSC Index Cycle as Management Withdraws Attention to Safety

According to Table 1, the lower limit is almost achieved at the end of year 10. Therefore, the scores of the five enablers and *Goals* at this point of time are used as the initial values for the simulation i.e. *Lds* score = 60.37, *Ppl* score = 68.07, *Prs* score = 82.23, *Pol* score = 73.17, *Pro* score = 132.44, and *Goals* score = 381.64 points. The simulation results (as shown in Figure 5 and Table 2) illustrate that at the beginning of the simulation, the CSC index, which reflects the fourth CSC maturity level, increases as the *Enablers* and *Goals*' scores increase, demonstrating safety improvement. At the end of year three, however, the CSC index reaches its specified upper limit, and management starts to unintentionally withdraw its attention from safety to other areas requiring improvement. Thus, there is a slight drop in the five enablers' scores, which leads to a decrease in the *Goals* and the CSC index scores. The CSC index continues to decrease gradually until it reaches the lower limit at the end of year eight. Subsequently, top management takes prompt actions to improve safety implementation, in response to the fear that the organization will fall to a lower maturity level (from the fifth to the fourth maturity levels). As a result, there is a relatively large increment in the *Lds* score from 60.41 points, at the end of year eight, to 79.58 points, at the end of year 10. The *Lds* action to improve safety implementation, obviously, enhances the implementation of the *Ppl*, *Pol*, *Prs*, and *Pro* enablers, leading to a higher *Goals* score and, ultimately, the CSC index. The actions taken to improve the CSC index continues until the index exceeds the assumed upper limit, then the '*attention withdrawal*' takes place again (top management shifts attention from safety to other areas for improvement), and the cycle continues. Simulation results show that the CSC index score oscillates between the fourth and the fifth CSC maturity levels. However, it slowly aims towards the maximum score of 1,000 point, over a very long term.

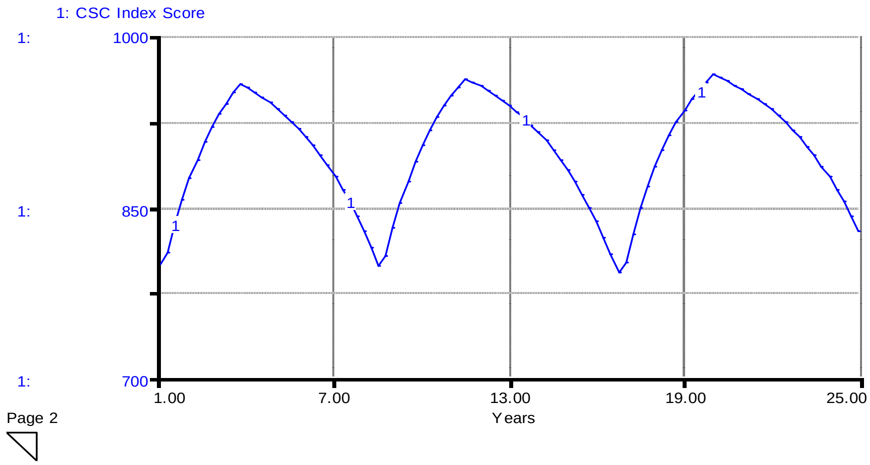

Figure 5: Graphical Results of the CSC Index as the Effect of the Attention Withdrawal

Table 2: Simulation Results of the Cyclical Style of Safety Management

Year	Score							
	Lds	Pol	Ppl	Prs	Pro	Enablers	Goals	CSC Index
Initial	60.37	73.17	68.07	82.23	132.44	416.28	381.64	797.92
1	72.05	76.76	75.79	86.46	136.87	447.93	426.25	874.18
2	83.05	78.62	81.56	88.54	138.78	470.54	460.13	930.67
3	89.63	79.21	84.07	89.17	139.33	481.42	472.84	954.25*
4	86.19	78.69	81.61	88.55	138.85	473.89	462.28	936.16
5	81.47	77.84	78.31	87.48	138.05	463.15	447.68	910.83
6	74.98	76.52	74.03	85.75	136.74	448.02	427.59	875.61
7	66.05	74.57	68.78	83.06	134.64	427.10	400.15	827.25
8	60.41	73.31	65.88	81.26	133.18	414.04	382.97	797.01**
9	63.96	75.31	70.31	83.95	135.54	429.08	401.28	830.36
10	75.98	77.86	77.65	87.33	138.20	457.02	446.37	903.39
11	85.94	79.11	82.85	88.93	139.31	476.14	471.15	947.29
12	89.27	79.28	83.68	89.12	139.45	480.79	475.09	955.88*
13	86.01	78.80	81.07	88.44	139.05	473.38	465.39	938.77
14	81.57	78.03	77.55	87.32	138.40	462.87	451.97	914.84
15	75.49	76.82	72.98	85.49	137.32	448.11	433.47	881.58
16	67.16	75.03	67.33	82.68	135.60	427.80	408.10	835.90
17	58.95	74.29	65.12	81.37	134.88	414.61	385.58	800.18**
18	71.62	77.28	73.85	85.96	137.86	446.58	437.68	884.26
19	81.81	78.83	80.36	88.30	139.16	468.46	466.43	934.89
20	90.90	79.53	84.64	89.34	139.68	484.10	482.00	966.10*
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
112	100.00	80.00	90.00	90.00	140.00	500.00	500.00	1,000.00

Note: * The CSC index reaches its upper limit. ** The CSC index reaches its lower limit.

6. Conclusion

Despite a large number of research studies focusing on measuring safety culture, virtually no research has been undertaken to investigate the interactions and causal relationships among the key factors of the CSC, and to assess the CSC maturity level and determine areas for improvement to progress through to higher maturity levels, over a period of time. This study, thus, develops a CSC dynamic model, utilizing the SD modeling, to capture the interactions and causal relationships among the six constructs of the CSC model, over a period of time. The CSC index, developed through the dynamic model, represents the sum of the five enablers and *Goals*' values at a point in time, and is used together with the five levels of CSC maturity to indicate the current CSC maturity level. The simulation results reveal that an organization with *ad-hoc* safety implementation should primarily focus on enhancing the *Lds* enabler to successfully progress through to higher CSC maturity levels in the future. A cyclical style of safety management is also modeled to imitate the situation where management withdraws its attention to safety when the CSC index exceeds the upper limit of management satisfaction with safety performance. This '*attention withdrawal*' negatively affects the *Enablers* and *Goals* scores, and ultimately the CSC index. The CSC index decreases as top management withdraws its attention from safety. This decrease continues until the index score reaches the lower limit. As a consequence of this fall, top management takes prompt actions to improve safety implementation, and thus to increase the *Enablers* and *Goals* scores, as well as the CSC index. Once again, the CSC index rises until it exceeds the upper limit, then management starts to withdraw its attention from safety again, and the cycle continues. While being affected by the cyclical nature of safety management, the organization, however, slowly progresses towards the maximum CSC index score of 1,000 point, over a very long period of time.

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