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A system dynamics view of a behavior-based safety program in the construction industry

Brian H.W. Guo[a,*], Yang Miang Goh[b], Karen Le Xin Wong[c,1]

[a] Department of Civil & Natural Resources Engineering, University of Canterbury, 69 Creyke Road, Christchurch 8140, New Zealand
[b] Safety and Resilience Research Unit (SaRRU), Dept. of Building, School of Design and Environment, National Univ. of Singapore, 4 Architecture Dr., Singapore 117566, Singapore
[c] Dept. of Building, School of Design and Environment, National Univ. of Singapore, 4 Architecture Dr., 11 Singapore 117566, Singapore

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ABSTRACT

Behavior-based safety (BBS) has received significant attention in the construction industry during the past decades. Ample evidence suggests that BBS is an effective accident prevention strategy. Past BBS literature is dominated by successful case studies, while unsuccessful cases and cases with mixed effectiveness in reducing unsafe behavior are limited. This paper reports a BBS program designed and implemented in the Singapore construction industry. The BBS program was aimed at reducing unsafe behavior in nine categories: lifting operations, excavation, working at height, work platform & access, manual handling, hot work (welding/gas cutting), plant & equipment, traffic management, and personal protective equipment (PPE). It consists of traditional BBS elements such as baseline observations, feedback, goal setting, and interventions. In contrast to other successful applications, the BBS program produced mixed results of safety behavior over 36 weeks. This paper adopts a system dynamics view to explain the mixed effectiveness. Causal loop diagrams were developed to capture behavior change mechanisms underpinned by reinforcement theory and goal setting theory, as well as dynamic effects of contextual and cognitive factors. It is concluded that the mixed effectiveness can be attributed to three main issues: dynamics of goal commitment, punishment, and monetary incentive. This paper adds to the body of knowledge of behavior safety program in terms of theoretical basis and implementation. By reviewing the BBS program holistically and reflecting upon the details of the case study, this paper offers lessons and reference for future design and implementation of BBS program in the construction industry.

1. Introduction

The behaviors that workers perform in their daily jobs can have a direct and immediate effect on health and safety. In the evolution of safety theories (or accident causation models) over the past decades, understanding and managing unsafe behavior has constantly been an important research topic. In the classic Domino Theory (Heinrich, 1931), unsafe behavior, together with unsafe conditions, was considered as root causes of accidents. According to Heinrich, among the direct causes, 88% are unsafe behavior, 10% are unsafe conditions, and 2% are unpreventable. Although causes of accidents have been extended up to supervision and top management level in later accident causation models (e.g., Swiss cheese model), unsafe behavior remained as one of the popular research topics in safety science. Guided by these models, significant research attention has been placed on identifying determinants of unsafe behavior and studying how to reduce unsafe behavior (Choudhry and Fang, 2008; Guo et al., 2016a,b; Seo, 2005).

Given the importance of safety behavior in accident prevention, behavior-based safety (BBS) has received significant attention since the 1970 s. There is no agreed definition of BBS, but it is often used as a catch-all term for a variety of safety interventions that focus on front-line workers' safety behavior (Wirth and Sigurdsson, 2008). It is a "bottom-up" approach which aims to identify and modify critical unsafe behavior through a combination of observation, feedback, training, and goal setting. Initial applications of behavioral techniques to safety can be traced back to the 1970 s when positive reinforcement was a core element of BBS programs. For example, Bird and Schlesinger (1970) used feedback and supervisory praise to reduce the unsafe behavior and improve safety performance. In the same period, Komaki et al. (1978) applied similar behavioral techniques to reduce unsafe behavior in food manufacturing industry. Efforts were made to control workers' psychological environment by defining and rewarding safe behaviors

* Corresponding author.
E-mail addresses: brian.guo@canterbury.ac.nz (B.H.W. Guo), bdggym@nus.edu.sg (Y.M. Goh), kwlx288@gmail.com (K. Le Xin Wong).
[1] Formerly.

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(Brown, 1977; Fitch et al., 1976). In the 1980s, Sulzer-Azaroff and Santamaria (1980) designed and applied a three-component package (i.e., feedback as to number and location of hazards, suggestions for improvement, and positive evaluation comments merited by accomplishment) to a group of university materials research laboratories.

In general, there has been ample evidence that BBS initiatives are effective to reduce unsafe behavior. For example, McAfee and Winn (1989) reviewed 24 studies of BBS and found that all supported the effectiveness of incentives or feedback in promoting safe behavior. In addition, Krause et al. (1999) undertook a longitudinal evaluation of an employee-driven behavior-based accident prevention initiative. Based on 5-year injury data from 73 companies, the study revealed that the average reduction of incidents from baseline amounted to 26% in the first year and increased to 69% by the fifth. In the construction industry, Mattila and Hyödynmaa (1988) examined whether BBS can be effectively used to improve safety at two building sites. Results suggested that BBS was effective to reduce accident rate and severity. Laitinen and Ruohomäki (1996) found that feedback and goal setting had positive effects on safety performance at two construction sites in Finland. Similarly, Duff et al. (1994) implemented and tested feedback and goal setting methods at six construction sites in the UK. Four safety behavior categories were focused, including access to heights, site housekeeping (tidiness), scaffolding, and use of personal protective equipment (PPE). Results indicated that the goal setting and feedback methods produced significant improvements in all safety behavior categories, except PPE. More recently, Choudhry (2014) developed and implemented a BBS program at construction sites in Hong Kong. Results suggested that BBS is an effective measure to reduce unsafe behavior when it is properly applied by committed management.

Despite the evidence, not all BBS programs brought about a sustainable reduction in unsafe behavior and improvement in safety performance. For example, following Duff's research design (Duff et al., 1994), Lingard and Rowlinson (1998) implemented BBS in the Hong Kong construction industry and found that the effectiveness of BBS was mixed in two behavior categories: heights and bamboo scaffolding. There was even a serious deterioration in safety performance of access to heights on one site. They explained the mixed effectiveness as a result of (1) lack of management commitment, (2) lack of resources, (3) goal rejection, and (4) a low level of hazard perception and recognition ability.

This paper reports a case study on a BBS program implemented in a construction project in Singapore. In contrast to successful applications aforementioned, the BBS program produced mixed results of safety behavior over 36 weeks. Thus, the first objective of this paper is to examine the BBS program from a theoretical perspective. The program structure and functions are identified and analyzed by consulting relevant theories, such as reinforcement theory (Skinner, 1938) and goal setting theory (Locke and Latham, 1990). The main purposes of the consultation are to (1) examine the mechanisms by which a typical BBS program reduces unsafe behaviors, (2) identify the possible factors influencing the effectiveness of the BBS program, and (3) identify and discuss possible limitations of the mechanisms. The second objective is to explain the mixed effectiveness of the BBS program from a system dynamics (SD) perspective. Causal loop diagrams (CLD) were developed which capture two different behavior change mechanisms underpinned by reinforcement theory and goal setting theory, as well as negative effects of contextual factors (e.g., production pressure, peer pressure, and goal conflict).

2. Literature review

2.1. Origin and evolution of BBS

BBS has its origins from behaviorism (also known as behavior modification, operant psychology, and applied behavioral analysis) (DeJoy, 2005). Behaviorism, initially developed by Watson (1924), defines behavior as a function of its consequences. As an external approach to human behavior, it explains and predicts human behavior in terms of environmental consequences. Internal mental, cognitive, and motivational processes are of less interest to behaviorists, although they do not deny the existence and importance of real causes of human behavior (Locke and Latham, 1990). Instead, they suggested that attention be paid on observable, objective, and practical facts, rather than elusive and unobservable internal processes (Luthans and Kreitner, 1975). Behaviorism adopts the classic stimulus-response (S-R) mechanism to *control* human behavior, which asserts that "*all learned behavior consisted of responses elicited by prior stimuli*" (Luthans and Kreitner, 1975). Watsonian behaviorism was considered as an adequate explanation of complex behavior and some reinforcement theorists (e.g., Edward L. Thorndike, Neal Miller, and B.F. Skinner) proposed the effect of reinforcement on human behavior (Luthans and Kreitner, 1975). Reinforcement theorists placed emphasis on consequences, rather than stimuli, for explaining behavior (Thorndike, 1913). Based on the work done by Watson and Thorndike, Skinner and his students developed an impressive theoretical base for so-called Skinnerian behaviorism. Skinnerian behaviorism follows the external approach to human behavior, but it sees the environment as a source of both prior and consequence stimuli to an objective behavior (Skinner, 1938). Instead of the traditional S-R mechanism, Skinner used a functional analysis which focuses on three major elements of the concept of contingency: cue, behavior, and consequence. Skinnerian behaviorists believed that behavior can be changed through the management of consequences. The organizational behavior modification framework developed by Luthans and Kreitner (1975) was largely based on the two schools of behaviorism.

BBS programs in recent years (e.g., (Choudhry 2014)) have integrated the goal setting theory developed by Locke and Latham (1990). Unlike the two schools of behaviorism, goal setting theory adopts an internal approach to human behavior. It explains and predicts human behavior by studying mental, cognitive, and motivational processes. Cognitive psychologists argued that human behavior cannot be explained without reference to consciousness and that learning and performance can occur without any external reinforcement (Locke and Latham, 1990).

2.2. Skinnerian behaviorism (reinforcement theory)

Reinforcement theory was initially developed by Skinner (1938) based on experiments using animals. Despite this, it is argued that the theory also applies to human behavior because of the fact that there is little difference between the learning that takes place in humans and animals. Reinforcement theory sees an individual's behavior as a function of its consequences; a behavior which is reinforced (i.e., rewarded) tends to be repeated and strengthened; punishment, as the opposite of reinforcement, weakens or eliminates a behavior (Skinner, 1938). Rewards and punishment create an environment in which humans are encouraged to shape or modify a targeted behavior(s). Based on a literature review of 24 BBS studies, McAfee and Winn (1989) proposed a hypothesized model that links positive reinforcement, situational variables, intermediate outcomes, and end result variables (see Fig. 1). It suggests that positive reinforcement delivers intermediate outcomes by changing situational variables, including environmental, individual, and task characteristics.

Positive reinforcement has been the most widely used component in BBS programs. It has gained popularity due to the fact that it avoided unwanted side effects of discipline and increased job satisfaction (McAfee and Winn, 1989). However, it has been criticized for overemphasizing external environments but ignoring internal cognitive and learning processes (Bandura and Walters, 1977; Locke and Latham, 1990). Reinforcement theory does not provide a theoretical explanation as to why a reinforcer (e.g., rewards) reinforces a behavior and what makes it work (Locke and Latham, 1990).