FACTORS THAT AFFECT CONSTRUCTION SAFETY EQUILIBRIUM: NAKHON RATCHASIMA CONSTRUCTION CREWS PERSPECTIVE

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Mostly construction workers' behaviours are shaped by task objective constraints and their capability during operating the task. Their behaviours seem to be a systematic migration toward to the boundary of functionally acceptable performance. It is forced by management pressure and an effort gradient of worker. This circumstance brings those workforces to the error margin and finally ends up with the accident. This research presents the Construction Safety Equilibrium Model (CSEM) which provides a balance between task demand (TD) and capability (C). The author investigated the factors that affect task demand and capability via Delphi process. The sample group was represented by 18 employees from various construction projects in the north-east province of Nakhon Ratchasima, Thailand, holding positions of civil engineer, safety officer and foreman. Results of the analysis showed that 1) the most significant factors of task demand were tools factor, work quality strictness factor and work pacing factor. The least significant factor was the physical site condition factor; 2) for capability; the highest significant factors were foreman communication ability factor, worker health condition factor and foreman work experience factor. Apart from that, the job training factor was the lowest significant factor. Regarding these results, both of the lowest significant factors from task demand and capability occupied the median value over 1.5 which meant that all 35 proposed factors remained.

Keywords: capability, construction safety, safety equilibrium, task demand.

INTRODUCTION

Construction work involves a lot of work processes which are subjected to change according to project-specific requirements and context. Moreover, the work environment is also change abruptly as dynamic condition. These changes create many chances of accidents and raised statistical number of construction trade occupational injuries (SSO 2013), (BLS 2012), (Haslam *et al*. 2005).

Human resource is the main workforce needed in the construction industry to accomplish its target. However, the results from Haslam *et al* (2005) research found that the main causal factor in construction accidents were problems arising from workers and brought into concern of worker behaviour while performing tasks. Their behaviours lead to risky conditions brought on by management pressure and their efforts often leads to an accident.

The less chance of risky conditions are beneficial to the construction trade. Thus, the risk condition will not occur as long as the construction projects have the effective

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Sooksil, N and Benjaoran, V (2015) Factors that affect construction safety equilibrium: Nakhon Ratchasima construction crews perspective *In:* Raidén, A B and Aboagye-Nimo, E (Eds) *Procs 31st Annual ARCOM Conference,* 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 539-548.

human resource management to deal with dynamic circumstances by assigning the right resource to the right task concerning safety and efficiency.

The present paper proposed the construction safety equilibrium model between task demand and worker capability could explain workers' behaviour tend to move into the risk condition. The Delphi Process has been applied to study the significance of the proposed factors for both task demand and capability. The least significant factors which received the median value below 1.5 (out of 5.0 scale) will be removed from the proposed model. The remaining significant factors will give consideration to classify the priority factor for practical purposes.

WORKERS' BEHAVIOURS DURING WORKING

Rasmussen (1997: 189) explains how the workers' behaviours tend to migrate closer to the boundary of functionally acceptable performance *"Human behaviour in any work system is shaped by objectives and constraints which must be respected by the all for work performance to be successful. However, aiming at such productive targets, many degrees of freedom are left open which will have to be closed by the individual worker by an adaptive search guided by process criteria such as work load, cost effectiveness, risk of failure, joy of exploration, etc. The work space within which the human workers can navigate freely during this search is bounded by administrative, functional, and safety related constraints. The normal changes found in local work conditions lead to frequent modifications of strategies and activity will show great variability. Such local, situation-induced variations within the work space call to mind the 'Brownian movements' of the molecules of a gas. During the adaptive search the workers have ample opportunity to identify 'an effort gradient' and management will normally supply an effective 'cost gradient'. The result will very likely be a systematic migration toward the boundary of functionally acceptable performance and, if crossing the boundary is irreversible, an error or an accident may occur."* As illustrated in Fig.1.

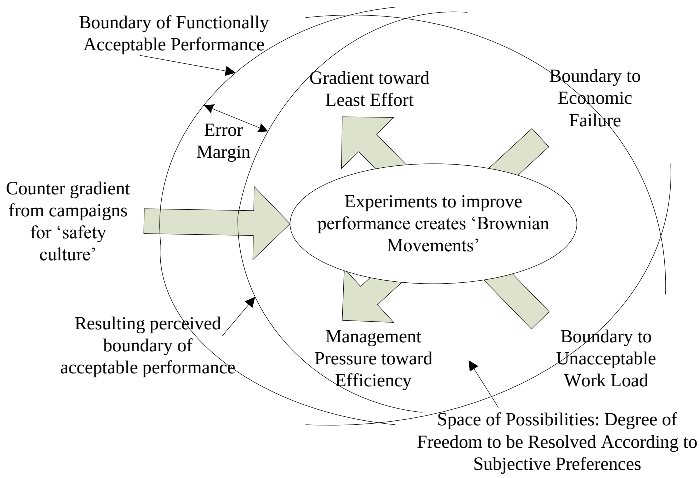

Figure 1: Rasumussen's work behaviour model (adapted from Rasmussen 1997)

Rasmussen's principle is grounded in Cognitive System Engineering: CSE which is concerned with the characteristics of the work system (the features of the task, tools, and work context) that influence the decisions, behaviors, and the possibility of errors and failures (Fuller 2005). Most applications of CSE to safety management are related to high-risk operations in complex systems such as aviation, health care, and nuclear and chemical plants. In the area of construction safety, Saurin *et al*. (2007) has implemented and examined site safety practices from a cognitive perspective.

Construction is a loosely coupled work system and leaves many degrees of freedom for the worker crew (Mitropoulos *et al*. 2009). It is only a suggested workflow but isn't required to follow the steps which left some spaces for the workforce to consider a appropriate choice of working decisions under dynamic situation (Saurin *et al*. 2008). These situations bring the workers' behaviour migration closer to the boundary of functionally acceptable performance and working in the boundary of error margin.

The implementation of safety rules and safety campaign in the construction trade is mostly prescribed *"safe behaviour"* (Mitropuolos *et al*. 2005) to keep workers' behaviour away from the boundary of functionally acceptable performance, however, the applied pressures are still pushing workers toward that boundary. Moreover, the development of construction technology and construction safety has been improved (Everett 1999), thus, human adaptation compensates for these safety improvements. This phenomenon has been observed in traffic research and explains why technological safety improvements have not generated the expected improvement in safety (Fuller 2005).

APPLIED TRAFFIC ACCIDENT MODEL IN CONSTRUCTION

The characteristics of traffic change all the time, this dynamic circumstance is similar to the changes in construction and it is supported by the study of road accidents in Fuller (2005) research. With Fuller's study (2005), Mitropuolos and Cupido (2009) have applied this principle in construction trade as well.

With regard to traffic accidents, the Task Demand-Capability Interface (TCI) model (Fuller 2005) provides a new conceptualization of the process by which collisions occur. At the heart of the TCI model is the relationship between the task demand and the capability applied to achieve a safe outcome while driving the vehicle. When the task demand is less than capability, the driver has control of the situation. Whereas, when the task demand is greater than the applied capability, the result is loss of control, which may result in a crash (or may not, if there is a compensatory action by others). The TCI model is illustrated as Fig.2.

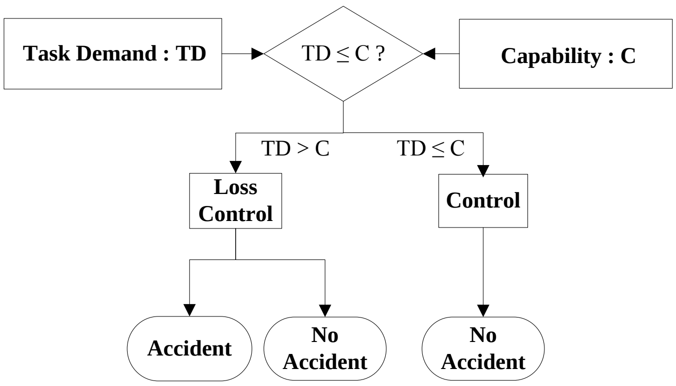

Figure 2: The Task Demand -Capability Interface model (adapted from Fuller 2005).

Task demands are determined by factors related to the vehicle, the road, the traffic conditions, the speed, and other tasks that the driver may perform. The driver's speed has a central role in safety and is affected by the driver's goals (such as minimizing time to arrival), as well as motives inherent in human behavior, such as maintaining speed and conservation of effort which makes the task demand not too high and can be paired with the low capability of the driver.

The applied capability relies on the driver's competence (training and experience), the level of activation, and human factors (fatigue, etc.). The level of task demand and capability changes over time, as both the driving conditions and the capability-related factors change. Moreover, task demand and capability are interdependent - changes in the perceived task demand change the driver's level of activation and consequently the capability. Thus, to maintain control, it is essential that the driver has effective anticipate to correctly assessing of the task demands.

In the experiment, the volunteers have to assess both task difficulty and statistical risk directly by viewing video sequences of roadway segments, filmed from the viewpoint of the driver, and travelling at different speeds. Participants were required to rate each sequence for task difficulty and for statistical risk of collision. The results found that speed was the driver's choice to control the difficulty level and balance the task demand with driver capability.

CONSTRUCTION SAFETY EQUILIBRIUM MODEL: CSEM

The proposed CSEM is synthesized from Rasmussen’s (1997) study which explains the workers’ behaviour migration toward the boundary of functionally acceptable performance and principle of traffic accident proposed by Fuller (2005). The CSEM was not based on unsafe acts and unsafe conditions as suggested by previous construction safety models but described individual workers’ behaviour that adjusted to fit with task demand and capability in each circumstance.

Using the construction safety equilibrium principle to explain accident situations.

With regard to Fuller’s principle (2005), traffic accidents that occurred due to task demands exceeding the driver’s capability thus creating uncontrolled situations. The Rasmussen (2007) principle claimed that the workers’ behaviour always migrates toward the boundary of functionally acceptable performance which is driven by 2 main pressures. The first is management pressure comparable to the task demand. The second pressure is the work effort comparable to worker’s capability. Whenever the task demand is greater than capability at that moment in time becomes the risk condition and creates the possibility of an accident.

For the proposed construction safety equilibrium principle, accidents will occur when workers are in the risk condition which the task demand is higher than capability and caused by either worker error or changes in working condition (Mitropuolos *et al*. 2005). There will not necessarily be an accident every time when workers are in that situation, but there is a possibility of an accident.

From this perspective, errors are defined as unattended actions that fail to achieve their intended outcome. Reason (1990) classified human error in three types: slips (unintentional loss of control), mistakes (selection of incorrect course of action) and perceptual errors. In the case of working among the risk condition with an error, this error pushes worker to reach boundary of loss control and ends up with an accident. If the worker can timely detect the error, that circumstance will become a controlled condition again.

For accidents caused by changes in working conditions such as losing soil stability abruptly, if the worker has the ability to react fast enough to avoid the event, then the incident is a near miss. In the event that the circumstance is very sudden, there is no time to react. Workers experience and situational awareness are needed.

The proposition of construction safety equilibrium model.

The construction safety equilibrium model develops with three key propositions:

1. Consideration for the task demand and capability are based on the working context to succeed in the intended outcome rather than in the working safety context, then matching the task demand level with capability level that were assessed from comprised factors in CSEM. This method will eliminate the conflicts among production and safety; in the short term these conflicts are usually resolved in favour of production (Reason 1990).

2. Construction accidents occur from task demand exceeding capability and result in various impact levels, this impact level depends on the difference between TD and C. The author proposed 5 impact levels, these impact levels are based on consideration of individual physical worker impact, not on property impact or other losses. The author assessed the lost work days of the injured workers and interpreted the cost by the daily wage of each worker.

3. This construction safety equilibrium model is a quantitative safety indices model rather than a qualitative model which safety and risk dimensions are very often taken seriously in some circles only when numbers or equations are illustrated (Le Coze 2015).

Principle of construction safety equilibrium model.

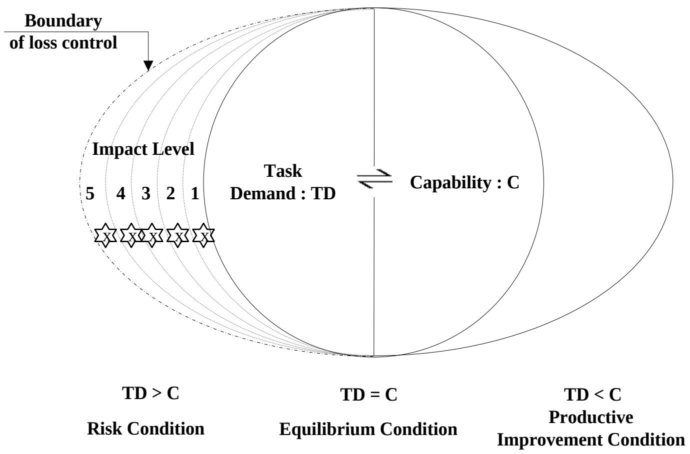

Figure 3: The construction safety equilibrium model : CSEM.

CSEM is the balance between task demand and capability as shown in fig.3. The conceptual framework displayed confirms the incident will not happen if the task demands equal capability and creates the equilibrium condition. And there would be no chance of accidents if the worker's capability is more than the task demand and the chance of productivity improvement are emerged. If the task demand is greater than the worker's capability, this puts that worker into the risk condition with the possibility of an accident. Whenever the mishap happens, it has an impact and varies by the difference between TD and C.

$$\text{Task Demand} - \text{Capability} = f(\text{Impact Level}) \qquad (1)$$

The impact level was analyzed by the difference between task demand and capability as computed by Eq. 1. The author proposed the impact level in 5 levels from very low, low, medium, high and very high. These impact levels are formed by the lost hours (in term of cost) and based on the assumption that each worker gets a different daily wage and depends on each worker's capability, therefore the same lost hours will have various values. Hence, the author proposed the impact level scale in terms of the lost work hours and interpreted this to cost as shown in table 1.

Table 1: Proposed impact level scale

TD - C	Impact Level (Baht)
0.01 - 0.20	Very Low (0 - 300 ฿)
0.21 - 0.40	Low (301 - 1,000 ฿)
0.41 - 1.50	Medium (1,001 - 10,000 ฿)
1.51 - 1.75	High (10,001 - 1,000,000 ฿)
1.76 - 2.00	Very High (> 1,000,000 ฿)

As previously mentioned, when the task demand becomes greater than capability, it also means that the assigned task is too difficult for workers to perform their jobs and brings the workers into the risk condition which will have a likelihood of an accident. Even if the accident does not happen in that situation, this would be a period of low production and high risk. In contrast with the case where the task demand is less than or equal to the capability, that task has zero chance of accident as it is a controlled condition. By the time that task demand is lower than capability, this task is easier for workers to perform and has the potential to improve productivity as well.

Prevention strategies by construction safety equilibrium principle.

The prevention strategies according to the construction safety equilibrium principle are maintaining the balance between task demand and capability under the concept of *"matching the right man to the right job"* and ought to have more value on the capability side in the event that workers' behaviour tended to migrate closer to the boundary of functionally acceptable performance (Rasmassen 1997). These workers' behaviour will increase the value of task demand as workers try to work more efficiently due to management pressure. In this situation, there is a need for error management and situation awareness strategies to prevent the accident (Mitropuolos *et al*. 2005).

DETERMINATION OF TASK DEMAND AND CAPABILITY FACTORS BY DELPHI PROCESS

After presenting the construction safety equilibrium model, the author introduced the determination of task demand and capability factors via the Delphi process. The Delphi method is a systematic and interactive research technique for obtaining the judgment of a panel of independent experts on a specific topic. Individuals are selected according to predefined guidelines and are asked to participate in two or more rounds of structured surveys. After each round, the moderator provides an anonymous summary of the experts' input from the previous survey as a part of the subsequent survey. In each subsequent round, participants are encouraged to review the anonymous opinion of the other panelists and consider revising their previous response. The goal during this process is to decrease the variability of the responses and achieve group consensus about the correct value (Hallowell and Gambatese 2010). Delphi is intended for use in judgment and forecasting situations in which pure model-based statistical methods are not practical or possible because of lack of appropriate historical /economic/ technical data, and thus where some form of human judge- mental input is necessary (Rowe and Wright 1999).

The author used the adapted Delphi process on the data collection phase by adding the group meeting method to shortening the length of the whole process. During the data collection phase, it was determined the proposed factors from literature reviewed of Mitropoulos and Cupido (2009), Haslam *et al*. (2005) Loughborough University and UMIST (2003). These proposed factors are concluded in the research by Sooksil and Benjaoran (2014). Furthermore, the author also added the results from the preliminary survey about the task demand factor and capability factor from the group of construction safety experts in high-rise construction projects in Bangkok, Thailand into the proposed factors as well. The participants who participated in determination factor by the Delphi process were 18 employees from various construction projects in the north-east province of Nakhon Ratchasima, Thailand. This province ranked first in number worker injuries and ranked in the top 3 for high injury rate per 1,000 full-time equivalent workers of the north-east region (SSO 2014). These 18 employees held engineer, safety officer, and foreman positions. They have been considered the significant of 23 task demand factors and 12 capability factors. The summary of determination factors that were used via the Delphi process are as follows:

- 2 rounds of surveys.
- After finishing each round, the moderator has given the group median of the previous round to participants before continuing to the next round.
- Some factors will be removed if it's received the group median below 1.5.
- The purpose of the process is to achieve a group consensus by examining the group quartile range, if less or equal 1.5 the process is ended.

RESULTS OF DETERMINATION FACTOR BY DELPHI PROCESS

The results of the determination factor by the Delphi process represented by 18 construction employees in Nakhon Ratchasima Province are shown in table 2 and 3.

Factors that affect task demand.

The completed determination process by the Delphi process found that none of the 23 factors (TD1-TD23) were removed because the group median was more than 1.5. In the 1st round of Delphi process, the median of all groups was higher than 1.5, but still didn't achieve group consensus by the 4 factors which their quartile range was over 1.5 and continued to the 2nd round survey. Before starting the 2nd round, the moderator provided the prior group median to the participants. For the 2nd round, the entire group median was still higher than 1.5 and the group consensus was not achieved by 2 out of 23 factors, unfortunately, due to the restricted data collection time, the process was stopped in 2nd round. (By the way, the author knows that all 23 factors have definitely not been removed.)

The highest group median was TD7: tools factor, which the sample group had been considered as the most influential factor to the task demand and made the task more difficult to perform as expected outcome most (group median = 4.22). The runner up was TD11: Work Quality Strictness factor that is controlled by the owner of construction project made more of an impact to task demand with 4.00 groups median. In third place was TD18: Work Pacing factor with 3.94 of group median. The increased pace made work more difficult which is similar to the study of traffic accidents which claimed that speed was the driver's choice to control the difficulty level (Fuller 2005). The least impacted factor was TD13: Physical Site Condition factor with 3.04 group median. The participants believe that most construction projects in Nakhon Ratchasima Province are not limited with physical site condition like those found in Bangkok.

Table 2: Determination results of task demand factors by the Delphi process.

Categorised Factor	Factor		Round 1		Round 2	
			Median	QR <= 1.5	Median	QR <= 1.5
Task Factor	**TD1**	Task Complexity	3.69	1.11	3.67	1.03
	TD2	Transportation of Material	3.33	1.19	3.35	1.03
	TD3	Work Co-ordination	3.25	1.03	3.35	1.03
	TD4	Working Area	3.69	1.18	3.67	1.10
	TD5	Type of Main Material	3.25	1.03	3.25	1.03
	TD6	Machine/Equipment	3.81	1.14	3.81	1.14
	TD7	Tools	4.19	1.14	4.22	1.04
	TD8	Designing	3.60	1.42	3.80	1.54
	TD9	Construction Method	3.58	1.33	3.57	1.15
	TD10	Engineering Criteria Strictness	3.71	1.21	3.71	1.21
	TD11	Work Quality Strictness	4.00	0.94	4.00	0.94
Environment Factor	**TD12**	Weather Condition	3.86	1.31	3.86	1.26
	TD13	Physical Site Condition	3.00	0.65	3.04	0.61
	TD14	Site Tidy, Cleanliness and Sanitatior	3.25	1.51	3.43	1.30
	TD15	Work Obstacle Condition	3.29	1.21	3.44	1.06
	TD16	Site Welfare	3.81	1.43	3.89	1.05
	TD17	Society and Environment Impacted	3.14	2.11	3.31	1.87
Work Behaviour Factor	**TD18**	Work Pacing	4.00	0.94	3.94	1.12
	TD19	Safety Rule Strictness	3.60	1.89	3.75	1.42
	TD20	Group or Individual Work	3.63	1.78	3.63	1.69
	TD21	Work Hour Restricted	3.33	1.19	3.35	1.03
	TD22	Number of Commander	3.40	1.49	3.56	1.06
	TD23	Abrupt Change of Working Method	3.71	1.28	3.89	1.01

Factors that affect capability.

None of the 12 factors (C1-C12) from capability were removed. In the 1st round, all group medians were higher than 1.5 and still did not achieve the group consensus by 3 factors and continued to the 2nd round with the informed prior group median. For the 2nd round, the entire group median was still higher than 1.5 and the group consensus was achieved with the process stopped.

The top 3 highest group medians were C12: Foreman Communication Ability factor, C3: Worker Health Condition factor, and C11: Foreman Work Experience factor with group medians of 4.73, 4.35 and 4.33, respectively. The overall outcome from the sample group found that the main influence factor of capability was mostly in the foreman categorized factor which is reflected in the situation upcoming workforces from neighbouring countries to each province of Thailand that will need a competent foreman to supervise these workers. The lowest group median factor goes to C2: Job Training factor with 3.56 due to the fact that most construction workers are foreigners, so construction companies are less motivated to provide job training.

Table 3: Determination results of capability factors by Delphi process.

Categorised Factor	Factor		Round 1		Round 2	
			Median	QR <= 1.5	Median	QR <= 1.5
Competence Factor	**C1**	Work Experience	3.95	0.85	4.04	0.71
	C2	Job Training	3.75	1.35	3.56	1.00
	C3	Worker Health Condition	4.29	1.21	4.35	0.97
Human Factor	**C4**	Hasten Behaviour	3.75	0.97	3.79	0.80
	C5	Fatigue	4.11	1.01	4.27	0.91
	C6	Frustration	3.60	1.89	3.92	1.50
	C7	Job Satisfaction	3.75	1.51	3.86	1.26
	C8	Working Relationship	3.86	1.40	3.86	1.31
Attention Factor	**C9**	Work Attention	4.00	1.53	4.25	0.97
	C10	Safety Awareness	4.11	1.01	4.15	0.93
Foreman Factor	**C11**	Foreman Work Experience	4.31	1.11	4.33	1.03
	C12	Foreman Communication Ability	4.65	1.03	4.73	0.91

CONCLUSIONS

The purposes of the current study was to present the principle of construction safety equilibrium, determine task demand factors and capability factors by 18 employees who were working in construction projects in Nakhon Ratchasima Province. The main conclusion is as follows;

The principle of construction safety equilibrium considers task and worker separately, and then employs the principle of matching the right man with the right job and then this situation will create the equilibrium condition between task demand and worker's capability. Consequently, the person in charge can perform the task productively without any accidents.

The results of the determination factor by 2 rounds of Delphi process indicate that none of 35 factors from task demand and capability were removed. These 35 proposed factors came from reference studies and the preliminary surveys of high-rise construction safety experts in Bangkok, Thailand. By the way, the median value of each factor can bring benefits to practitioners by prioritise those factors as their shown significance and it provides practitioners with strategies to assign the right worker to the suitable task.

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