VALIDATION OF CONSTRUCTION SAFETY EQUILIBRIUM MODEL ON HIGH-RISE BUILDING CONSTRUCTION PROJECT IN THAILAND

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Construction work involves a lot of work processes which are subjected to change according to project-specific requirements and context. These changes can cause accident hazards which require workforce management to balance task demand with worker capability. This research proposed the construction safety equilibrium model which was based on the car accident model. This study investigated the factors that influence task demand and capability, and also determined the weight of each factor by the Analytic Hierarchical Process via interviewing construction safety experts. The 15 accident case studies of workers who worked in high-rise building construction projects were applied for validation of the model. The research came up with two results: 1) the highest weight of the main factor of task demand contributed to the work behaviour factor and rule of safety was the most weighted sub-factor; for capability, the dominant main factor was the human factor and frustration was the highest weighted for the sub-factor; and 2) the average task demand level and the average capability level of the sample group was 1.99 and 1.77 of 3.00 point scale. These scores reflect the work that workers were performing when the accidents occurred were too difficult and did not match their capabilities according to the principle of construction safety equilibrium.

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

INTRODUCTION

The construction industry has a large number of activities with complex processes which affect the high risk of accidents. The record of occupational injuries in Year 2011 by Thailand Social Security Office (2011) found that the construction trade occupied third place in work-related fatalities with the number of 87 fatal injuries from a total of 590. For an international view, the construction industry in the United States accounted for 738 fatal cases from a total of 4,693 fatal cases and was ranked second for the highest number of fatal work injuries (BLS, 2011).

Other interesting information from the Bureau of Labour Statistics (2011) identified falls from a higher level accounted for 553 fatal work injuries, and in the construction trade, falls are the most frequently occurring types of accidents resulting in fatalities (Hinze, 1996). Research by Haslam *et al*. (2005) referenced statistics which stated that the construction industry accounted for 31% of all work related fatalities in 2002/03 of which 46% were caused by falls. For decades, high-rise building construction workers have worked in one of the highest-risk workplaces in Taiwan, more than150 high-rise

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building construction workers are killed in workplaces annually, representing one-fourth of the work-related death toll in Taiwan (Hsu *et al.*, 2008).

Human resource is the main workforce needed in the construction trade to accomplish its target. Most successful projects have effective human resource management to deal with dynamic circumstances in the project, these environments created several of the risks that are confronted. Thus, worker management tools would be useful for 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, investigated the factors which influence task demand and capability and found the weight of each factor by Analytic Hierarchical Process, and lastly, validated the proposed model with a construction worker sample group who have been injured during the operation of the task.

FUNDAMENTAL OF CONSTRUCTION SAFETY EQUILIBRIUM MODEL

The literature review began with the study of the Fuller (2005) traffic collisions model which explained the principle of a car accident. Afterward, Mitropoulos and Cupido (2009) applied the Fuller (2005) theory in the construction trade. Finally, an investigation of the factors that are related to the construction safety equilibrium model by Haslam *et al*. (2005), research which found the causal factors of 100 case accidents.

Traffic collisions model

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. As shown in Fig. 1, 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).

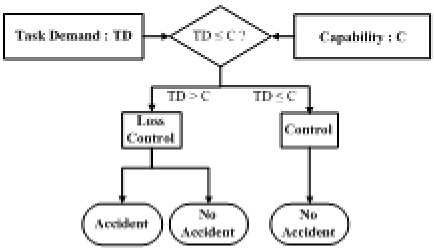

Figure 1: The Task Demand -Capability Interface model (adapted from Fuller, 2005).

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 result from the study found that speed is the driver's choice to control the difficulty level and balance the task demand with driver capability.

Applying Fuller model on construction trade

Mitropoulos and Cupido (2009) applied traffic collision principles in construction accident occurrence. The component of Task Demand and Capability described below.

Task Demand

Task demand can identify the level of task difficulty to accomplish the production task under various circumstances and try to avoid the hazards. The greater the task demand is the greater likelihood of error and loss of control of the process.

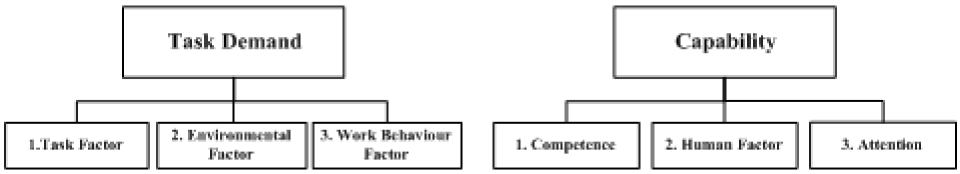

Figure 2: The factors of Task Demand and Capability (adapted from Mitropoulos and Cupido, 2009).

Fig. 2 groups task demand factors into three categories: (a) Task factors; (b) Environmental factors; and (c) Work behaviours. For example, the task demands for a crane operation depend on task characteristics (type of load, distance and angle, blind lift), environmental factors (soil stability, wind, visibility, proximity with power lines), and work behaviours (such as speed or other tasks that the operator may perform).

Capability

The applied capability determines the ability to deal with the task demands, and depends on: (a) The competency of the worker(s), including work experience, training, skill and physical condition; (b) Human factors that can reduce competency, especially four key factors related to accidents: rushing, fatigue, frustration, and satisfaction; and (c) The level of attention given to the task and the hazards. Attention is a limited resource - multiple task demands (due to task complexity) reduce the attention to any single demand, and distractions can divert the attention from the task or the hazards.

Furthermore, Mitropoulos and Namboodiri (2011) assessed the task demand by The Task Demand Assessment: TDA, which is a new technique for measuring the safety risk of construction activities and analyzing how changes in operation parameters can affect the potential for accidents. TDA quantifies the *"task demand"* of actual operations based on characteristics of the activity and independent of the workers' capabilities. The task demand reflects the difficulty to perform the activity safely. The paper presents the findings from the initial implementation of TDA and demonstrates its feasibility and applicability on two different operations: a roofing activity and a concrete paving operation. It displays how the TDA method can compare different production scenarios and measure the effect of production factors on the accident potential. Unfortunately, this paper did not investigate the capability assessment for both operations.

From those details, it proves that the Fuller principle can be adapted to the construction industry. However, the investigation of the capability assessment and identification of factors related with task demand and capability are essential.

Causes of construction accidents

Haslam *et al*. (2005) presents overview findings from Loughborough University and the UMIST (2003) full research report which studied the casual factors of construction accidents. Based on a focus group of a variety of stakeholders in the construction trade to discuss and propose the root causes of accidents, the report detected the main causes of 100 incidents and assessed the possibility of consequences impacting each incident. They claimed that more than one-third was judged to have had the potential to result in a fatality, while more than two-thirds could have led to a serious injury. Levels of involvement of key factors in the accidents were problems arising from workers or the work team; workplace issues; shortcomings with equipment (including PPE); problems with suitability and condition of materials; and deficiencies with risk management. Meanwhile, they proposed a hierarchy of causal influences in the construction accidents model as well.

From that point of view, the author categorized each factor that influences task demand and capability into the construction safety equilibrium model which will be discussed next.

MODEL DISCUSSION

After reviewing the background model which involved safety equilibrium and influence factors of construction accident causes, a construction safety equilibrium model is proposed based on Fuller (2005) TCI model with the principle of *"The accident won't occur, if the task demand is not greater than worker capability at that moment in time "* as Eq.1

$$\text{Task Demand} \leq \text{Capability} \quad (1)$$

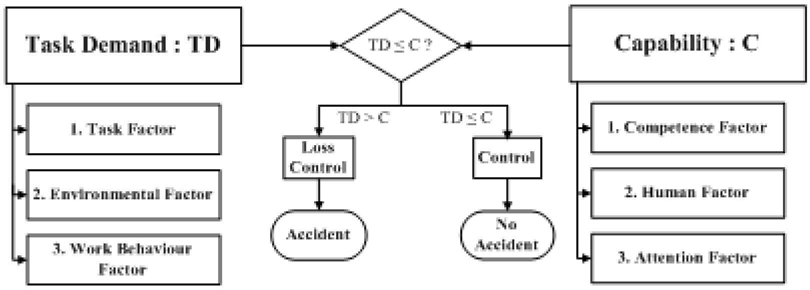

Figure 3: The Construction Safety Equilibrium Model between Task Demand and Capability

And whenever the task demand exceeded capability, the result is loss of control and accident occurred. This means that the task is too difficult for the worker to handle. Whereas, when the task demand is less than the capability then that task is controlled and the worker can perform that task easily. As shown in fig.3.

The Construction Safety Equilibrium Model is comprised of task demand and capability with the 6 main factors from the Mitropoulos and Cupido (2009) research. For sub-factors, the author synthesized from Haslam *et al*. (2005) and Loughborough University and UMIST (2003) exploration and grouped these sub-factors into categories as show in fig.4.

This model assesses both task demand and capability into quantitative terms for the macro level of high-rise construction project in Thailand, contrasts with Mitropoulos and Namboodiri (2011) research that tried to quantify only the task demand of actual operations based on characteristics of the activity and independent of the workers' capabilities.

WEIGHTING FACTORS

All factors were included in The Construction Safety Equilibrium Model; therefore, giving weight to each factor which can then be used to generate quantitative safety indices. The weighted factors generated by the implementation of a multi-attribute decision making tool to draw knowledge from experts in the field. Shapira and Simcha (2009) is one of the sample researches that adopted Analytic Hierarchical Process (AHP) for a decision making tool to elicit knowledge from experts and formalize it into a set of weighted tower crane safety factors. Construction equipment and safety experts were interviewed and led through the AHP process to provide their assessments on the relative importance of safety factors obtained in an earlier study. The AHP process is provided the weight for each safety factor and is shown the dominant factors that are vital for focusing.

The AHP process (Saaty, 2008) has been used for weighting each factor by interviewing 5 construction safety experts in high-rise construction projects. These 5 experts had a cumulative 55 years in their current (2014) positions, with an average of 11years, and three of them had shared a total of 45 years' experience as senior safety officers. They were all experienced in high-rise building construction projects in the domestic area. All of them expressed their opinions and experiences through interview forms and the conversations between the participants and author were recorded.

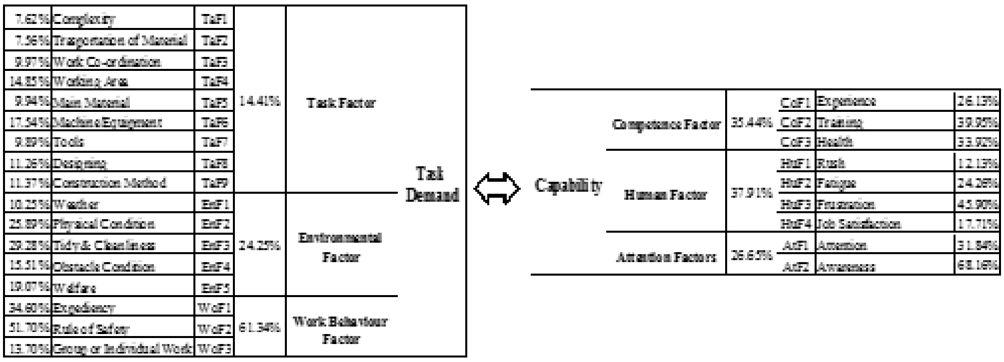

Figure 4: The factors of Task Demand and Capability and weighted of each factor.

The data was analysed and the results were verified by measuring Consistency Ratio (CR), which is a tool for controlling the consistency of pair-wise comparisons. The final weighted factors are shown in figure 4.

VALIDATION OF THE MODEL

In order to validate the application of the construction safety equilibrium concept to the construction safety trade, the author validated the model by applying it to a sample group of 15 incident cases (non-fatal cases due to the need of receiving information directly from the victim). These 15 injured workers held a variety of positions at the worksite. Six of them were employed as carpenters and the rest were employed as masons, safety crew members, levellers, foremen and hoist operators. Four of these victims held Cambodian citizenship. The investigation used a designed interview form and a voice recorder along with the interview process by individual case. The participants were asked to consider the accident situation and describe the task demand and their capabilities.

Task demand level

Table 1 indicates that the average task demand level of the sample group was 1.99 out of 3.00 which is over a half and as such is considered a difficult task to perform.

Table 1: Valued of each factor of Task Demand

Task Demand Factors			Task Factor (14.41%)									Environment Factor (24.25%)					Work Behaviour Factor (61.34%)		
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Frequency			Complexity	Transportation of Material	Work Coordination	Working Area	Main Material	Machine/Equipment	Tools	Designing	Construction Method	Weather	Physical Condition	Tidy & Cleanliness	Obstacle Condition	Welfare	Expedition	Rule of Safety	Group or Individual Work
			TaF1	TaF2	TaF3	TaF4	TaF5	TaF6	TaF7	TaF8	TaF9	EnF1	EnF2	EnF3	EnF4	EnF5	WoF1	WoF2	WoF3
Frequency of Chosen Level	Low	1	1	4	4	0	4	2	6	4	4	2	2	3	8	0	2	0	0
	Medium	2	12	7	11	12	11	7	9	10	10	11	2	11	4	9	9	12	12
	High	3	2	4	0	3	0	3	0	1	1	2	2	1	2	6	4	0	3
Average Each Sub Factors			2.07	2.00	1.73	2.20	1.73	1.87	1.60	1.80	1.80	2.00	1.60	1.87	1.33	2.40	2.13	2.00	2.20
Factor Weight			0.011	0.011	0.014	0.021	0.014	0.022	0.014	0.016	0.016	0.052	0.060	0.071	0.058	0.049	0.212	0.317	0.086
Value (x Factor Weight)			0.023	0.022	0.023	0.047	0.023	0.047	0.023	0.029	0.029	0.100	0.100	0.133	0.083	0.121	0.453	0.634	0.188
Average Task Demand Level			1.993																

The rule of safety was the highest sub-factor at 0.634 or 31.81% of the average task demand level and proved that the task demand level or difficulty level of the entire sample group depended on project safety rules. As some of the projects abandoned rules of safety (not behaving under the rules) then there was a consequence of a higher level of task difficulty. All workers started to be more aware of the risk when completing a task. Another dominant sub-factor that impacted the task demand (22.73%) was expediency, working at a faster rate made the work more difficult. With regard to the traffic accident principle by Fuller (2005), it was found that drivers adjust their speed based on task difficulty. The transportation of material was the less affected sub-factor with only 1.10%.

Capability level

The average capacity level of the sample group was 1.77 and lower than the average task demand by 0.22 as shown in table 2. The explicit evidence indicates that at the time of accident, task demand was greater than worker capability

Two sub-factors which have a high potential level of affecting worker capability were frustration and awareness. According to information from the interviews with the sample group, in most cases they were worried about their own problems and not aware of the risks involved. These two sub-factors decreased worker capability according to the Hinze Distraction Theory (1996).

Table 2: Valued of each factor of Capability

Capability Factors		Capability								
		35.44%			37.91%				26.65%	
		Competence Factor			Human Factor				Attention Factor	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Experience	Training	Health	Brain	Fatigue	Frustration	Job Satisfaction	Attention	Awareness
Frequency		CoF1	CoF2	CoF3	HuF1	HuF2	HuF3	HuF4	AtF1	AtF2
Frequency of Chosen Level	Low 1	7	8	0	4	4	3	0	2	6
	Medium 2	4	6	15	10	11	12	13	13	9
	High 3	4	1	0	1	0	0	2	0	0
Average Each Sub Factors		1.80	1.53	2.00	1.80	1.73	1.80	2.13	1.87	1.60
Factor Weight		0.093	0.142	0.120	0.046	0.092	0.176	0.067	0.085	0.182
Value (x Factor Weight)		0.167	0.217	0.240	0.083	0.159	0.313	0.143	0.158	0.291
Average Capability Level						1.772				

Comparing task demand level with capability level

Table 3: Comparing Between Task Demand Level and Capability Level of each incident

Accident Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average
Task Demand Level	2.29	1.67	2.23	1.69	2.22	1.90	2.11	2.08	2.18	1.92	1.93	2.02	1.88	1.85	1.90	1.99
Capability Level	1.33	1.63	1.69	1.86	2.14	1.50	2.09	2.00	1.59	1.70	1.91	2.00	1.77	1.68	1.68	1.77
Difference	0.96	0.05	0.53	-0.17	0.08	0.40	0.02	0.08	0.59	0.22	0.02	0.02	0.12	0.17	0.23	0.22

Referring to table 3, the average task demand level and average capability level of the sample group was 1.99 and 1.77, respectively, with a difference of 0.22. According to the principles of construction equilibrium, these figures show the tasks that the workers were doing at the time of the incident were too difficult for them to achieve. Except in the 4th case, the task demand level was lower than the capability level by -0.17. In this case, miscommunication during conversation via interpreter should be the main cause of error.

The widest gap between the task demand level and capability level was the 1st accident case with a difference of 0.96. In this case, the victim was a young outside labourer with no previous experience and had been recently hired before accident.

The 7th, 11th and 12th accident cases occupied the least difference between the task demand level and capability level by 0.02. These circumstances were nearly balanced for both sides, but working negligently or loss of attention to work can initiate the accident.

CONCLUSION AND DISCUSSION

This research proposed the principle of the construction safety equilibrium, and investigated factors and reflected weight factors in the model, then validated the presented model with a sample group. Conclusion and discussion follow.

Weighted factors

The sample group insisted that work behaviour factors were the major factors affecting the task demand level rather than task factors or environmental factors. This result contradicted Loughborough University and UMIST (2003) research that found task factors such as design or construction methods were the main root causes of accidents.

Human factors seem to have more weight than the competence factor; this is reflected in the situation of a skill shortage in the workforce in the Thailand construction trade and being replaced by non-work experienced labourers from neighbouring countries.

Equilibrium of Task Demand and Capability

The 15 cases of accidents were a sample group for the research and have a task demand and capability level of 1.99 and 1.77, respectively. The sample group responded that the tasks were too difficult for their capabilities, and this resulted in accidents. The rule of safety and expediency were the sub-factors that most influenced the task demand level to reach the maximum 3 point scale. On the other side, reduced worker capability depended on frustration and awareness sub-factors.

Overall, the 15 accident cases corresponded with the principles of the construction safety equilibrium that the author proposed. The case of the task demand being lower than worker capability means the worker can perform the task without any accidents and also means that the task is too easy and can be improved for higher productivity.

LIMITATION AND FUTURE STUDY

The weight of each factor represented opinions from only 5 construction safety experts, which is probably not representative of the entire construction industry. Other representatives from the construction sectors and qualified experts have to be added.

Referring to surveying period, the rating scale of each factor needs more clarification and the addition of the exact meaning of each rating level (low, medium and high). The author has to repeat the question and explain the meaning of the rating system several times.

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